William Mulholland

Chief Engineer and Builder of the
Los Angeles Aqueduct

Complete Report on Construction of the Los Angeles Aqueduct

WITH INTRODUCTORY HISTORICAL SKETCH

ILLUSTRATED WITH MAPS, DRAWINGS AND PHOTOGRAPHS

Published by the
DEPARTMENT *of* PUBLIC SERVICE
of the City *of* Los Angeles

1916

PRINTED BY
THE STANDARD PRINTING CO.
OF
LOS ANGELES

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INTRODUCTORY HISTORICAL SKETCH

OF THE

LOS ANGELES AQUEDUCT

BY ALLEN KELLY

A drop of water, taken up from the ocean by a sunbeam, shall fall as a snowflake upon the mountain top, rest in the frozen silence through the long winter, stir again under the summer sun and seek to find its way back to the sea down the granite steeps and fissures. It shall join its fellows in mad frolics in mountain gorges, singing the song of falling waters and dancing with the fairies in the moonlight. It shall lie upon the bosom of a crystal lake, and forget for a while its quest of the ocean level. Again it shall obey the law and resume its journey with murmurs and frettings; and then it shall pass out of the sunlight and the free air and be borne along a weary way in darkness and silence for many days. And at last the drop that fell as a snowflake upon the Sierra's crest and set out to find its home in the sea, shall be taken up from beneath the ground by a thirsty rootlet and distilled into the perfume of an orange blossom in a garden of the City of the Queen of the Angels.

—ALLEN KELLY, 1905.

The construction of the aqueduct that brings the waters of Owens River across 250 miles of desolate and rugged country to the City of Los Angeles set a new standard of public service for American municipalities. No other public work at all comparable in magnitude to the aqueduct has been accomplished within the limits of cost and time fixed by the engineers in their first estimates. It is not an exaggeration to say that the builders of the aqueduct established a world's record of efficiency and economy. They promised that the work should be done in five years, and water delivered at the San Fernando reservoir at a cost of $23,000,000. They began work in 1908, and they brought the water to San Fernando in 1913 at a cost within the original estimate.

For several years the men, upon whom rested the responsibility of providing the City of Los Angeles with sufficient water for her people, sought in vain for sources of permanent supply equal to prospective demands. The necessity for additional supply was made plain to the Water Commissioners in 1904, when for ten days in July the daily consumption of water exceeded the inflow into the reservoirs by nearly four million gallons. Excessive consumption was checked by the use of meters, and some small additions to the supply were obtained from wells, but the rapid increase of the city's population made such relief only temporary, and the Board was confronted by a problem of serious proportions. The Board imposed upon Engineers Wm. Mulholland, J. B. Lippincott and O. K. Parker the task of gathering data and finding a solution of the problem, and their report in 1905 showed the hopelessness of seeking relief in any watershed south of the Tehachapi. There is water under the ground of all the coastal plain in which the city stands, but it is not an inexhaustible reservoir, and the drafts made upon the underflow by the pumps of thousands of farms and orchards were found to be steadily lowering the plane of saturation. To take more water for the city from the underground reservoir would stop the development of the surrounding country and set a limit to the growth of Los An-

geles. The engineers were forced to the conclusion that nowhere in the basin south of the Tehachapi range and west of the San Bernardino could Los Angeles obtain any considerable flow of water without taking it from the lands which produce the wealth of Southern California.

In estimating the future needs of the city, the engineers assumed a rate of growth based upon the average for the ten preceding years and predicted an increase from 200,000 population in 1905 to 250,000 in 1912, and 390,000 in 1925. Assuming a reduction of average consumption of water, by the use of meters, to 150 gallons a day for each inhabitant, the city would require in 1925 a supply of 90 second feet or more than 58,000,000 gallons a day, which is more than double the minimum flow of the Los Angeles River, and ten second feet in excess of the recorded maximum flow at the narrows.

The City, however, failed to keep within the limits of the growth diagram drawn by the engineers, and by 1910, as shown by the Federal census, its population had reached the figure set by them for 1918, viz: 319,000. According to the diagram in the report of the engineers, the city would have a population of half a million in the year 1936. As a matter of fact, it reached that stage of growth in 1913. Fortunately, a seven-year period of abundant rain brought the flow of the Los Angeles River up from the forty second feet of 1905 to 70 second feet in 1911, nearly doubling the city's supply from that source. Heavy draughts were made by pumps upon the ground waters, lowering the water plane from six to nine feet, and the per capita consumption was decreased by the extended use of meters to 138 gallons a day. Because of the series of wet seasons and the resort to the temporary expedient of robbing the agricultural lands of the coastal plain of their ground waters, the city escaped a water famine during the period of its wonderful growth, but there was no margin of safety, and the lowering of the ground water plane confirmed the judgment of the Water Board and its engineers in seeking other sources of supply.

Early in 1905, a solution of the water problem was suggested to Water Superintendent Mulholland by Fred Eaton, who had been City Engineer and Mayor of Los Angeles. Mr. Eaton had interests in Inyo county, and for many years had been making extended trips through the valley of Owens River, which lies between the Sierra Nevada and ranges of desert mountains on the eastern state line. In the valley Mr. Eaton had seen vast floods of water pouring wastefully from the Sierra snowfields into Owens Lake, a dead sea of the Inyo desert, where hundreds of thousands of years of evaporation and condensation had produced a saturated solution of soda salts, and he had wished that those floods could be available to the great city which he saw growing in the Southland.

On his journeys to and from the valley, Eaton studied the country with the eye of an engineer, and he saw that in some past geologic period the river, flowing for 100 miles along the eastern foot of the Sierra, had been a great torrent, swinging around the end of the range and pouring into the basin of the Mojave desert. Volcanic action had cut off the flow by throwing a barrier across the south end of Owens Valley and forming the enclosed basin in which the lake lies. But the barrier was low, and below it the old stream route was still open to within a few miles of the Southern California plain, the only obstacle being the range of mountains north of Los Angeles.

Confident that a constantly descending route for the river could be found, Eaton made surveys from Owens Valley to the mountains north of the city, and proved the practicability of his dream. And then he waited for the time when Los Angeles should realize her need and be ready to consider the bold undertaking of bringing water 250 miles across the desert and piercing a mountain range to make way for the conduit. He waited many years, never doubting that the city of his dreams would become a reality, and when the Pueblo awoke, found itself a city of measureless possibilities and began to take thought of providing for its future, Eaton confidently laid the foundation of his

Close View. Head of Cascade at Outlet of Los Angeles Aqueduct.

great water project by making contracts for the purchase of lands controlling water rights and reservoir sites on Owens River, and taking options from riparian owners.

Eaton felt so certain that Owens River was the only available supply adequate to the needs of the city, that he formed his plans to carry out the project as a private enterprise in case the city should hesitate to take up a work of such magnitude. He figured that he could supply the city with water and electrical power, and make the enterprise pay, and he found capitalists who agreed with him and were eager to take up the project. Others also had seen the possibilities of profit in such an enterprise, and one of the electric power companies had made plans for bringing water and power from Owens River to Los Angeles, but had been checked by the inauguration of an irrigation project by the Reclamation Service.

Land bought by Eaton included the reservoir site of the irrigation project, designed to reclaim desert public lands in the upper end of Owens Valley. Against a private enterprise, the Reclamation Service could exercise the right of condemnation. As against a municipality seeking water for a large urban population, the government would not persist in its project, its policy being to promote the good of the greatest number. Eaton therefore laid his plans before Superintendent Mulholland and suggested that the city take over his contracts and options and carry out the project as a public enterprise, which would be aided instead of opposed by the Federal government.

Mulholland made a trip over the route and a general examination of the hydrography of Owens Valley, and was impressed by the possibilities of the scheme. Then he studied the problem in detail, plotted an approximate line, and made an estimate of cost that was confirmed later by thorough instrumental surveys and minute calculations. He made a report to the Water Board and outlined an aqueduct and reservoir system, which he estimated would cost, including the purchase of land and water rights, about $25,000,000. He recommended Eaton's proposals to the Board, and the Board had the courage and confidence to accept them and to use its own funds in taking over Eaton's contracts and options before making the project public.

The Board of Water Commissioners was composed of John J. Fay, Jr., Fred L. Baker, J. M. Elliott, M. H. Sherman and Wm. Mead.

In April, 1905, Messrs. Fay and Elliott, accompanied by Mayor McAleer, City Attorney Mathews, and Messrs. Eaton and Mulholland, made a visit to the Owens River Valley, for the purpose of further investigating the water conditions existing there, and of considering a proposal from Mr. Eaton to sell and transfer to the city his options and contracts for the purchase of lands and water rights along the Owens River.

After carefully considering all available information concerning sources of water supply, sufficient for the needs of the city, both in and outside of Southern California, the Board became thoroughly convinced that the Owens River afforded the only adequate supply that could be obtained by the City at a cost which it would be justified in incurring. Having reached this conclusion, the Board entered into a contract with Mr. Eaton for the acquisition of the property embraced in the proposal submitted by him, and devoted the available funds of the Water Department to this purpose. This property included most of the riparian lands for a distance of about forty miles along the river above Owens Lake, in Inyo county, and a reservoir site in Long Valley, in Mono county.

In August, 1905, the Board of Water Commissioners and Mr. William Mulholland took into their confidence Mr. J. O. Koepfli, President of the Chamber of Commerce, and stated to him that they had found in the Owens River Valley a source of supply that would furnish Los Angeles with all the water that it would ever need. President Koepfli immediately took the matter up with the Board of Directors of the Chamber, and in conjunction with other commercial bodies sent a special committee, consisting of H. C. Witmer, M. Lissner and Fred A. Hines, to the Owens River Valley to make a personal investigation, especially with

reference to the quality of the water. The committee obtained samples of the water and had them analyzed both at the State University and in Los Angeles.

As soon as this investigation was completed an election was called to vote $1,500,000 in bonds for the purchase of land and water rights in the Owens River Valley, the Chamber of Commerce strongly urging the people to vote the bonds, and the following report of a special committee was given to the public:

"By careful investigation we have endeavored to secure all the information possible in connection with the proposed plans. We have conferred with the city officials, the water board and with disinterested engineers and contractors. We have examined maps and government reports and have joined with other commercial bodies in sending a special committee consisting of H. C. Witmer, M. Lissner and Fred A. Hines to the Owens River Valley to make a personal investigation, especially with reference to the quality of the water, of which a number of analyses were made by different chemists.

"From this inquiry the conclusion of your committee may be thus summarized:

lusions. "First—It is imperatively necessary to secure a new water supply if the development of this city is to be continued.

"Second—The Owens River Valley is the only source that promises a permanent supply that will be sufficient.

"Third—There is an ample supply for our needs, and the quality of the water is satisfactory.

"Fourth—There are no difficult engineering problems presented in building the conduit needed. It is a large but simple proposition.

"Fifth—The estimates of cost of construction are very liberal and the total outlay will probably come well within the estimate made by Mr. Mulholland, engineer of the Water Department.

"Sixth—While there will undoubtedly be more or less litigation as in all enterprises of this character, we believe that the rights sought to be acquired by the city can be successfully maintained and defended.

"In connection with the above conclusions we desire to express our satisfaction with the skill and marked ability displayed by those officials of the city who have had charge of its interests. A project of this kind conducted by a municipality usually fails or becomes a matter of great expense by reason of premature knowledge of the plans.

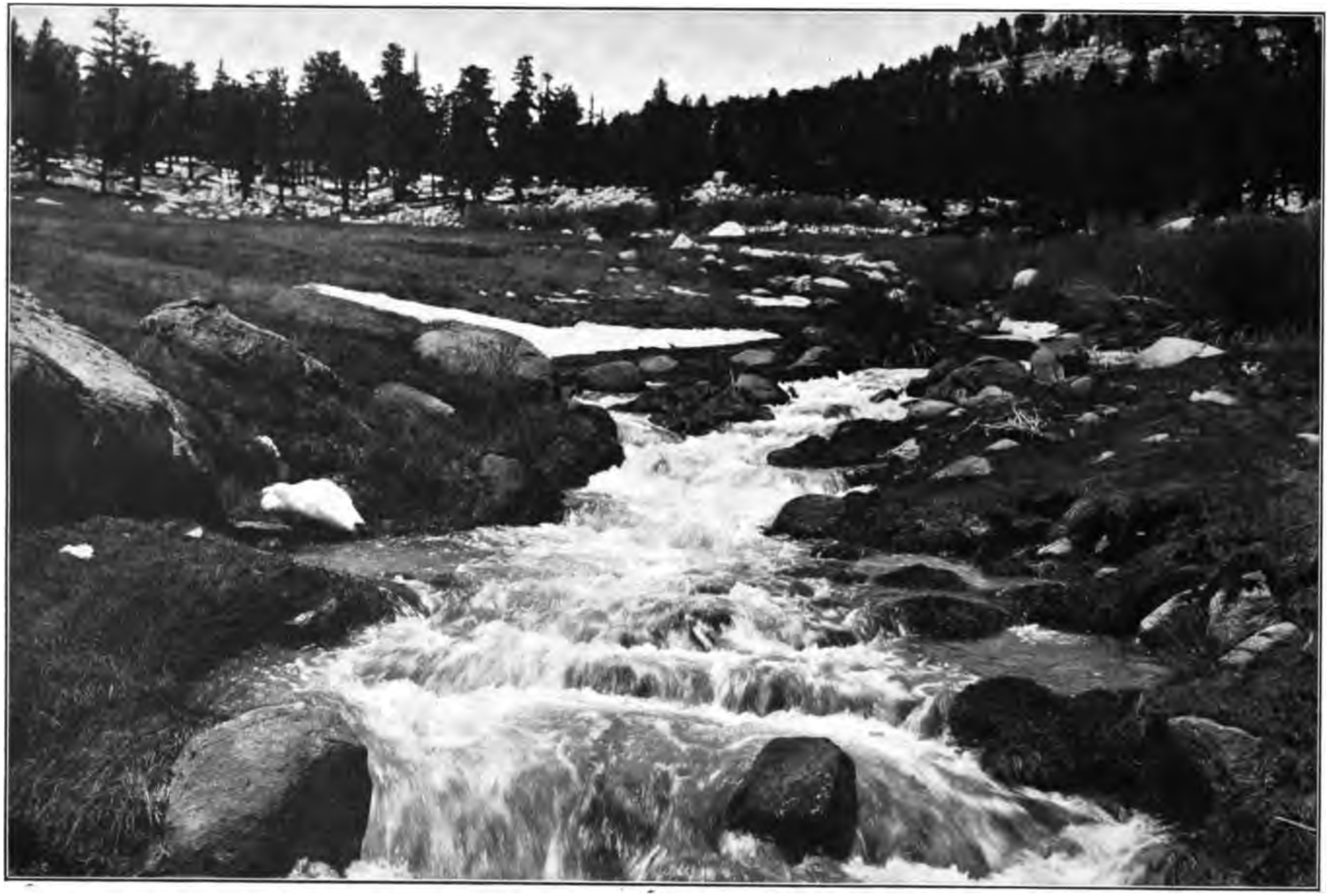
"We believe that they were sufficiently informed on all material points involved in the enterprise to justify the action taken by them. They do not expect to expend any more money than is necessary to conserve the city's interest until they shall have secured the approval of the entire plans by disinterested experts of the highest character.

"We heartily approve the entire project and recommend that the bonds be voted."

(Signed)
W. J. Washburn,
Willis H. Booth,
A. B. Cass,
William D. Stephens,
Jacob Baruch,
Fred A. Hines.

The Owens River project was made known to the people of the City of Los Angeles in July, 1905, and was received with enthusiastic approval as the only practicable and adequate answer to the most vital question confronting the city. The Water Board asked the city to issue bonds for $1,500,000 for the purchase of lands and water and the inauguration of work on the aqueduct, and on September 7, 1905, by a vote of 10,787 to 755, the citizens of Los Angeles approved the bonds and endorsed the Owens River project.

In November, 1906, the city employed three of the most eminent hydraulic engineers in the United States to examine and report on the project. The consulting engineers were Frederick P. Stearns, president of the American Society of Civil Engineers and member of the Isthmian Canal Commission; John R. Freemen, one of the greatest specialists in hydraulics in the country; and James D. Schuyler, builder of the largest dams in the West, and an engineer of wide experience.



"DOWN GRANITE STEEPS"—(LITTLE COTTONWOOD CREEK)

The Consulting Board made its report on December 25, 1906, showing that a supply of 20,000 miner's inches of water could be obtained from Owens Valley, and that the cost of building an aqueduct to bring it to San Fernando, including purchases of land and water rights, would be $24,485,600. The engineers said: "We find the project in every respect feasible, and that it involves no great difficulties of engineering or construction other than those arising from mere length and distance" They also declared the water to be of good quality for domestic use, and in conclusion the greatest engineers in America paid this high compliment to Eaton, the dreamer, and Mulholland, the designer: "We find the project admirable in conception and outline and full of promise for the continued prosperity of the City of Los Angeles." The engineers estimated the time of construction, after the sale of bonds, as five years.

In 1907, the question of issuing bonds for $23,000,000 for the construction of the Los Angeles Aqueduct was submitted to the people by the City Council, and a campaign of education was carried on by the civic and commercial bodies and the press. The Chamber of Commerce, the Merchants and Manufacturers Association and other organizations investigated the project thoroughly, the Mayor and Council scrutinized it in detail, engineers studied it and reported their conclusions, and on June 12, 1907, the people of Los Angeles endorsed the project by voting in favor of the bond issue. The vote was in the ratio of ten to one.

From the time of the first issue of bonds, the aqueduct project ceased to be under the jurisdiction of the Water Board and came under control of the Board of Public Works, which was composed in 1907, of James A. Anderson, Albert A. Hubbard and David K. Edwards. However, because of the great public confidence in the Board of Water Commissioners and their special knowledge of the subject, the Board of Public Works consulted and co-operated with the Water Board, and all important actions were taken as the result of joint conferences. An Advisory Committee was appointed by the two boards to handle details and organize the working force of the aqueduct. This committee consisted of the president of the Board of Public Works, president of the Water Board, Chief Engineer Mulholland, Assistant Chief Engineer J. B. Lippincott and Attorney W. B. Mathews. Some changes in the personnel of the Board of Public Works occurred during the progress of the work. President Anderson retired and was succeeded by Gen. Adna R. Chaffee, and Mr. Edwards was succeeded by W. M. Humphreys. In 1912, Gen. Chaffee and Mr. Humphreys retired and Lorin A. Handley and Edward Johnson took their places. When the Board of Public Service was created by charter provision, taking the place of the Water Board, its first president, Major H. T. Lee, and Electrical Engineer E. F. Scattergood, of the Power Bureau of the new board, were added to the Advisory Committee. Major Lee was succeeded in 1912 by President F. G. Henderson, and he in 1913 by President R. F. Del Valle.

In obtaining rights of way and control of surplus water in Owens Valley, the city was aided materially by Director Walcott of the Geological Survey, Chief Engineer Newell of the Reclamation Service, Chief Forester Gifford Pinchot, U. S. Senator Frank P. Flint and other Federal officers. The Reclamation Service abandoned its Owens Valley project in favor of the city, and the Federal officers named joined with a committee of the Chamber of Commerce in presenting the matter to President Roosevelt and securing his approval of a bill confirming the city's right to use such public lands as it might require. A special right of way act was passed by Congress in June, 1905, granting free right of use to the City of Los Angeles of all public lands required for canals, reservoirs and power plants in Inyo, Kern and Los Angeles counties. President Roosevelt, in order to still further assist the city, withdrew by executive order all lands in bulk along the line of the proposed aqueduct and in Owens Valley, which might be of possible use to the city, and which might be filed upon by individuals or corporations prior to the

time when the city could complete its surveys and file definite maps.

The general plan of the aqueduct, as outlined by Mulholland and approved by the Advisory Board of Engineers, subject to such modifications and changes of location as might be found advisable during progress of the work, was as follows: an intake on Owens River about thirty-five miles north of the point where the river empties into Owens Lake; an open canal of 900 second feet capacity through Owens Valley, 23 miles unlined and 37 miles lined with concrete, to Haiwee reservoir at an elevation 200 feet above the level of Owens Lake; Haiwee reservoir, to accumulate and store the waters of the river and of intercepted streams flowing down the east side of the Sierra Nevada, having a capacity of 63,800 acre feet or 20,890,000,000 gallons; from Haiwee to Little Lake, 15 miles of lined and covered conduit of 420 second feet capacity; Little Lake to Indian Wells, 24 miles of conduit, tunnels and siphon pipes; Indian Wells to Red Rock summit, 20 miles of conduit, flumes and siphon; Red Rock through the "bad lands" of Jawbone Canyon to the Mojave desert, nearly nineteen miles of tunnels, siphons and conduit; through the Mojave desert to the west end of Antelope Valley, 68 miles, mostly of concrete conduit; reservoir at Fairmont to regulate delivery of water through pressure tunnel; Elizabeth Lake tunnel, 26,870 feet; power drops in San Francisquito Canyon; tunnels, siphons, flumes and conduit, and the small compensating Dry Canyon reservoir to San Fernando reservoir, 15 miles; total, 225.87 miles, exclusive of reservoirs and power water ways.

A vast amount of preparatory work had to precede aqueduct construction, and that was begun in the fall of 1907. It was believed by the engineers that the time of completion of the aqueduct would be controlled by the driving of the longest tunnel, and, therefore, the portals of the Elizabeth tunnel were opened simultaneously with the beginning of preparatory work along the line, but with that exception no permanent work was begun until October, 1908. Crews were organized and camps established in September, but construction dates from October 1, 1908.

In the first eleven months, twenty-two miles of tunnel were driven, sixteen miles of cement conduit completed, four miles of open canal in Owens Valley dug, and a rate of progress established that would have brought the water into the San Fernando reservoirs in the fall of 1912 had there been no delay in providing funds.

The hardest part of the work was tackled first, and it was done for less than the estimated cost, and in much less than the estimated time. The engineers might have concentrated their forces on the easier work of conduit building in the open country and made a spectacular showing in mileage for the first year, but their efforts were guided by expediency alone.

Before work could be begun on the aqueduct, it was necessary to build roads and trails, power plants, telegraph and telephone lines and provide water supply for camps established along 150 miles of waterless desert.

Included in this work were 215 miles of road, 230 miles of pipe line, 218 miles of power transmission line and 377 miles of telegraph and telephone line. Fifty-seven camps were established along the line of work, most of them in the mountains, and good roads made to reach them. Some of the roads challenge comparison with the finest mountain roads in California, and all of them are better than the stage roads existing in the desert before the City began its work.

The problem of transportation of material through the desert to construction camps between Mojave and Owens Valley was solved by the building of a branch of the Southern Pacific Railroad, known as the Nevada & California Railway, from Mojave to a junction with the narrow-gauge line in Owens Valley. The road is of standard gauge, laid with heavy steel, and is a permanent part of the Southern Pacific's system. It was built in accordance with a traffic agreement with the city and was completed in October, 1910. The city also built a temporary line about nine miles long from the main line into the Jawbone division

"MAD FROLICS IN MOUNTAIN GORGES"—(MAMMOTH CREEK)

by way of Red Rock. When this track had served its purpose, it was taken up and sold for $30,000, a part of the material being bought by the U. S. Government and used in the building of levees on the lower Colorado.

Materials for making cement were found on the Cuddeback ranch five miles east of Tehachapi on the main line of the Southern Pacific. The city bought 4300 acres of land, covering limestone quarries, clay deposits and deposits of tufa, and built a cement mill of a designed capacity of 1000 barrels of Portland cement a day. This plant is known as the Monolith mill. It was found that the grinding of tufa with an equal quantity of Portland cement doubled the volume and made a satisfactory quality of concrete, producing a material identical with the cement used by the Romans in their imperishable work. Tufa cement does not acquire hardness as rapidly as straight cement, but at ninety days in such sheltered work as tunnel lining and sub-surface conduits, it exceeds straight cement in strength and continues to improve with age long after the time at which Portland cement reaches its maximum hardness and strength. In addition to the output of the Monolith mill and the tufa grinding plants at several points on the line of the aqueduct, the city used 200,000 barrels of cement bought from other sources. More than a million barrels of cement were used. This made enough concrete to have built a road 12 feet wide, 6 inches thick, from Portland, Oregon, to Yuma, Arizona.

In the acquisition of water rights and for operation, maintenance and protection of the aqueduct, the Board of Public Works bought 124,929 acres of land in the drainage basin of Owens River, 4300 acres near Tehachapi, 69 acres for yards at Mojave and 5818 acres for reservoir sites; total, 135,116 acres, exclusive of canal rights of way. This is an area double the total area of the City of Los Angeles at that time.

World's records for speed, efficiency and economy were made by the tunnel drivers on the aqueduct. The American record for hard-rock tunnel driving—604 feet in one month—is blazoned above the south portal of the Elizabeth tunnel. This bore through the mountain, 26,870 feet in length, 10 by 12 in diameter, and having a capacity of 1000 cubic feet of water per second, or 27,000,000 gallons an hour, was driven and lined for two-thirds of the estimated cost and in two-thirds of the time allotted by the Board of Consulting Engineers.

When this tunnel work was started, it was estimated that a reasonable progress for each end would be eight feet per day with three eight-hour shifts, and a bonus schedule was adopted by the Board of Public Works which provided that each man working in the tunnel would receive a bonus of 40 cents for each foot that this schedule was exceeded. This bonus was paid in addition to the regular wages, the men receiving these wages whether the bonus schedule was exceeded or not, and the bonus being distinctly a reward for extra exertion. The effect of the bonus was to increase the daily wage of the men about 30 per cent. and to decrease the cost of driving per foot from 10 to 15 per cent. There was a further saving to the city in expedition of the work and in early release of equipment for use elsewhere.

From the South Portal, 13,500 feet of tunnel were driven and from the North Portal, 13,370 feet. The average progress for the two headings for the 1215 days' work was 22.1 feet, or a little better than 11 feet per day for each end. The connection was made of the two headings on February 28, 1911, after the expiration of forty months of work. (The time which the Board of Engineers estimated as necessary to complete this was five years.) The center line of the tunnel met within 1⅛ inches and the grade checked within ⅝ inch.

A noteworthy record was made in driving the Red Rock Tunnel. This tunnel is in an indurated sand or soft sandstone, and is 10,596 feet in length. Excavation was started on May 27, 1909, and completed January 24, 1910. The Red Rock tunnel crew raced with the Swiss drivers of the Loetchberg tunnel for the world's record, and won it. In August, 1909, the Swiss broke their own previous record by driving 1013 feet, working with four air drills in one heading. Tom Flanigan's crew at Red Rock, working with hand drills in one heading,

drove 1061 feet. The hard-rock men in the Elizabeth tunnel raced with the government crew on the Gunnison tunnel, and beat them. There are 142 tunnels, aggregating 43 miles in length, in the aqueduct, and about 9 miles of power tunnels.

Some of the heaviest and most difficult work on the line was in the Jawbone division, which comprises a stretch of very rough mountain and canyon country intervening between the Indian Wells Valley and the Mojave Desert. In this division lies the mass of deeply eroded sandstone and indurated drift known as the Bad Lands.

The aqueduct passes through the mountains of Jawbone division in a series of tunnels of varying length, connected by short stretches of conduit, and crossing the deeper and wider canyons in inverted steel siphons. The Jawbone siphon is the most imposing piece of work on the aqueduct. Its total length is 8,095 feet and it varies from 7 feet 6 inches to 10 feet in diameter. The steel plate of which this pipe is built is 1⅛ inches thick in the heaviest section. The maximum head on the pipe is 850 feet, and its total weight is 3,216 tons. It is the most noteworthy pipe in the United States.

The longest siphon on the aqueduct is the pipe crossing Antelope Valley. It is 21,767 feet in length, and up to heads of 80 feet is built of concrete, the remaining 15,597 feet being steel pipe. The concrete and steel pipes are both 10 feet in diameter. The maximum head on this siphon is 200 feet, and the weight of the steel is 3,511 tons.

There are 98 miles of covered conduit south of the Haiwee reservoir. The covering was not included in the original estimate of the Board of Engineers, but it was a part of the original plan. The engineers said they would save enough on the tunnels to pay for the cover, and it so proved. The covering cost more than a million dollars.

The first reservoir on the line is at Haiwee, seven miles south of Owens Lake. The area of the water surface is 2,100 acres and the capacity of the reservoir is 63,800 acre feet, or enough water to run the full capacity of the aqueduct for 80 days.

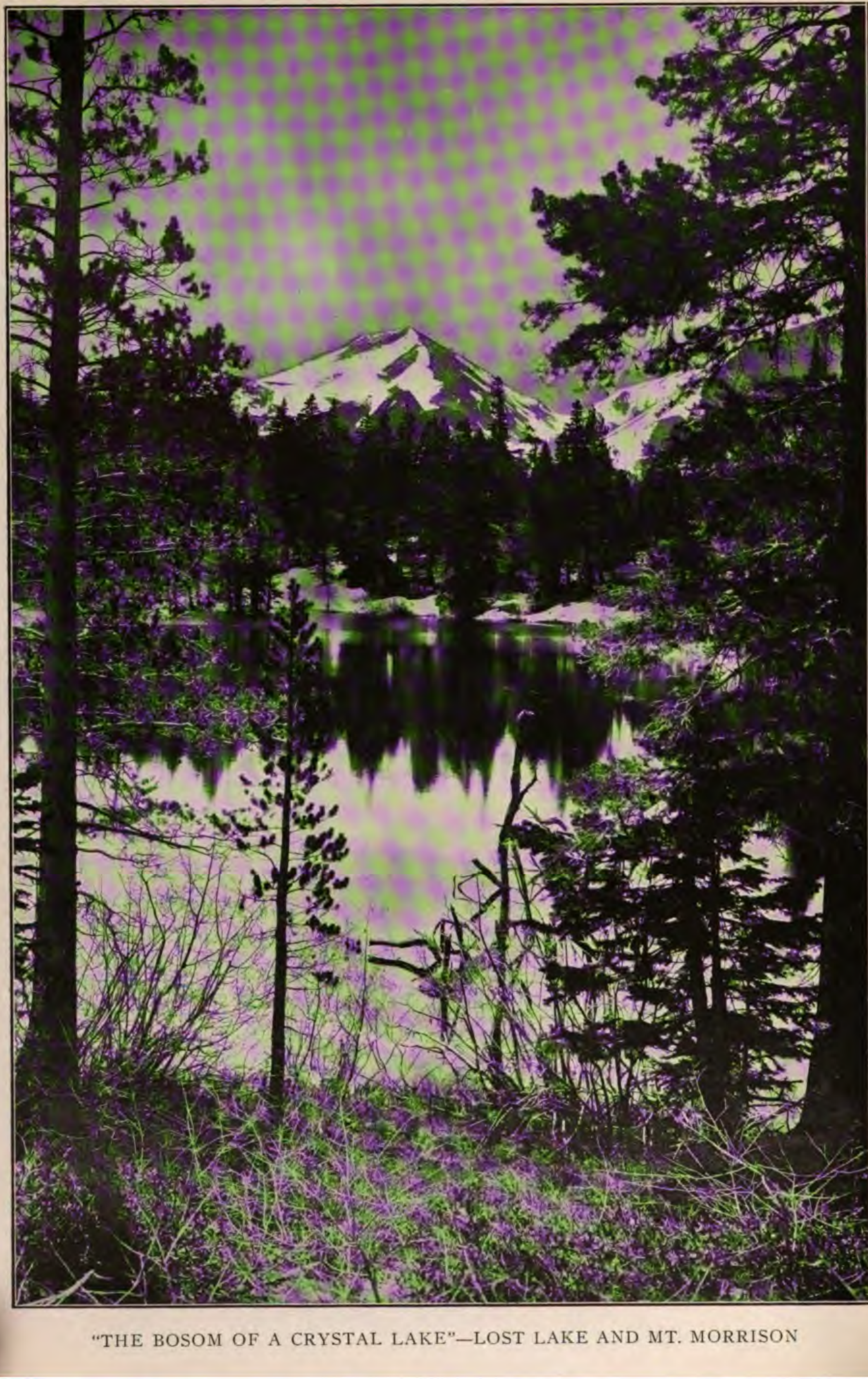
The surface elevation of the water is 3,764 feet above sea level, and the bottom 3,690 feet, which gives a 74-foot depth of water when full. The reservoir has a length, along its central axis, of 7.4 miles, having precipitous sides which gives it a comparatively great average depth, a fact which makes for the preservation of the water in a potable condition. Since the water has to traverse the whole length of the reservoir to reach its outlet, the well-known sanitary effect of prolonged storage of water is attained to the fullest extent.

The next reservoir on the line, known as the Fairmont Reservoir, which is located on the south side of the Antelope Valley, and at the immediate head of the long Elizabeth tunnel, has a capacity of 7,620 acre feet, and is also so situated that the water flows in at its farthest end and is required to traverse the reservoir throughout its greatest length to escape through the outlet, the sides being, as in the Haiwee reservoir, precipitous so that the average depth of water is great, the surface elevation being 3,036 feet above sea level, and the bottom elevation 2,940 feet above sea level.

The Fairmont reservoir is intended not only as a safeguard in the shape of a storage supply 200 miles from the intake, but also as a means for regulating the hourly fluctuation of water through the power plants located below, to meet peak load conditions.

The Dry Canyon reservoir on the Saugus division, located a short distance below the lower of the San Francisquito power plants, has a storage capacity of 1,325 acre feet and its province is to regulate back to uniformity the irregular flow that may be discharged through the power plants.

The Aqueduct discharges at its lower end into a reservoir known as San Fernando Reservoir No. 2, now under construction and being so far advanced that it is capable of being used to the capacity of about 6,000 acre feet. This capacity will be increased when the dam is finished, to about 23,000 acre feet. The reservoir is situated about two and one-half miles from the end of the Aqueduct, there being another reservoir site available intervening, which will be known as San Fernando Reser-



"THE BOSOM OF A CRYSTAL LAKE"—LOST LAKE AND MT. MORRISON

voir No. 1. The capacity of this reservoir, when built, will be 15,000 acre feet.

Neither one of these sites is very favorable to reservoir construction as the yardage in their confining dams, which will be of earth, is enormously disproportionate to their capacities, No. 1 requiring over 2,700,000 cubic yards of earth and No. 2 in excess of 2,000,000 yards. Conditions are favorable, however, in both cases for economical hydraulic construction, as the material is favorable in both quality and proximity.

These reservoirs are extremely valuable features of the Aqueduct as they enable its retention in commission through the winter, thereby affording a water supply for the power plants along the line and providing also for the heavy summer draft of irrigation water which, during the irrigating season, will be much in excess of the capacity of the Aqueduct to supply.

The city also owns a reservoir site in Long Valley in the northerly portion of the drainage basin of Owens River, having a tributary watershed of 391 square miles. If this reservoir should be constructed, the flow line would be at an elevation of 6,810 feet, the area of its water surface would be 8,686 acres, and its storage capacity would be 340,980 acre feet. This would call for a dam 520 feet long on top and 160 feet in height. A structure of this character would make this one of the notable storage reservoirs in the United States. It may be found desirable to build this Long Valley reservoir when the complete flow of the aqueduct has been utilized. In this event, its province would be to hold over a water supply from years of excessive flow for such years of drouth as may occur once in a generation.

A second great reservoir site is controlled by the city at a point about six miles north of the intake of the canal. This is known as the Tinemaha reservoir site. Its flow line would be at an elevation of 3,887 feet. The area of its water surface would be 7,074 acres, and its storage capacity would be 127,325 acre feet, with an earthen dam 40 feet high. This reservoir site has the advantage of being situated near the intake of the canal, and below the canals of the valley users, and the city owns continuously both sides of the river from the dam site to the intake, thus offering protection from trespass to any waters which might be discharged from it.

The capacity of the Long Valley reservoir would be sufficient to furnish a continuous flow of the full aqueduct for a period of 427 days, and the Tinemaha reservoir, with the height of dam given, for a period of 159 days.

In addition to this, eleven wells have been put down in the bottom lands of Owens Valley along the line of the canal, and ten of these have struck artesian water. This body of underground and artesian water in Owens Valley is about fifty miles in length, and is largely controlled by the city. A complete study of this basin is reported by C. H. Lee in Water Supply Paper No. 294, the report being based on investigations made at the instance of the City of Los Angeles.

More than six million pounds of blasting powder were used by the builders of the aqueduct, and yet only five men were killed in accidents due to explosives in underground work. This record is remarkable. The comparative freedom from accidents with powder in the Los Angeles work is not attributed wholly to superior skill and carefulness of the men having charge of blasting operations. It was due in a great measure to the use of the most perfect fuse obtainable regardless of cost. Only the highest quality of German fuse was used, and it was submitted to the most rigorous tests for accuracy of timing and for reliability; tests that the cheaper American fuse failed to meet.

An idea of the magnitude of the Los Angeles Aqueduct enterprise may be derived from comparison with projects that might be undertaken by other cities. For instance, conduits of the same length would carry water from Lake Ontario to New York; from Lake Champlain at the Canadian line, or from the Penobscot River above Bangor, to Boston; from Lake Erie to Louisville; from Lake Michigan to St. Louis; from Kern river, or from the McCloud at Shasta, to San Francisco; from Klamath Lake to Portland, Oregon; from the Rhine at Frankfort to Berlin; from Lake Geneva to

Paris. The length of the aqueduct equals the greatest width of England, or the length of Ireland from Belfast to Queenstown.

Efficient machinery is an important factor in expedition of construction, and the Aqueduct availed itself of all new devices that would expedite the work, but the unprecedented speed and economy of work on the Los Angeles Aqueduct were due to the men behind the machines. The organization was fortunate in securing the services of a remarkable body of efficient men as engineers and superintendents, and to the interest and intelligent zeal of these men much of the success of the undertaking must be attributed. The practice was to leave the widest discretion to the man on the job, and the results amply justified it.

The remarkable efficiency records made by division engineers and superintendents of construction on the aqueduct attracted the attention of engineers and great contracting companies, and when these men finished their work for Los Angeles, their services were in demand wherever big work was going on. An engineering company, having trouble in driving a difficult tunnel in Spain, engaged at a large salary one of the men who broke the record in the Elizabeth tunnel, and sent him to Barcelona to solve its problems. Another went to the Argentine on a big public work, and the man who made the record drive in the Red Rock tunnel went to the Catskill Aqueduct. All over the world, the capable builders of the Los Angeles Aqueduct are doing big work and making good on their well-earned reputations for efficiency.

The aqueduct was completed within the original estimated cost and without additional bonds or financial assistance; the finishing touches, repairs, clean-up, etc., being paid from funds provided by sale of plant and equipment.

The work was really done for about two and a half millions under the estimate, as additional work was paid for out of the funds, which work was not contemplated by the Board of Consulting Engineers, nor included in the estimate of $24,500,000.

In addition to the additional expenditure, the aqueduct suffered considerable loss on account of the temporary shut-down in the summer of 1910, caused by financial stringency. At the time of the shut-down there were approximately 4000 men in the field, and in a few weeks the force had been reduced to less than 1000 men.

The loss of organization, decrease of efficiency and resulting increase of unit costs when the forces were reorganized, caring for plant and equipment temporarily idle, and the delay of the time of completion is conservatively estimated to have cost at least $250,000.

With the exception of power tunnels in San Francisquito canyon, the conduit line was completed early in 1913, and it was expected that water would be flowing into the San Fernanao reservoir in June of that year. But there was one section in the security of which the engineers did not have great confidence. They had changed the original plan for a steel siphon across Sand canyon, and tried the experiment of making pressure tunnels in the rock on both inclines. The formation seemed to be massive granite, but the first pressure developed indications of fissures and leakage. In May, 1913, a large head of water was turned into the conduit from Haiwee reservoir to make a final test of the rock siphon, and the incline tunnels failed spectacularly. The south incline blew out, and the side of the mountain was lifted bodily and shattered into a mass of debris, a result not wholly unexpected or surprising to the engineers.

Substitution of a standard steel siphon for the Sand Canyon rock tunnels delayed final opening of the aqueduct several months, and water did not come through to San Fernando until November 5, 1913, when the arrival of water from Owens valley was the occasion of a great public celebration. In the presence of thirty thousand citizens, the gates at the south portal of the terminal tunnel were opened, and a flood of clear water plunged down the cascade into San Fernando valley. The Chief Engineer was called upon to make an address presenting the water to the people of Los Angeles, and he made a record for concise public speech-making. As the water came foaming

Collapsed Antelope Siphon

Returning to Form Under Water Pressure

Partly Restored to Form

Completely Rounded Out by Pressure

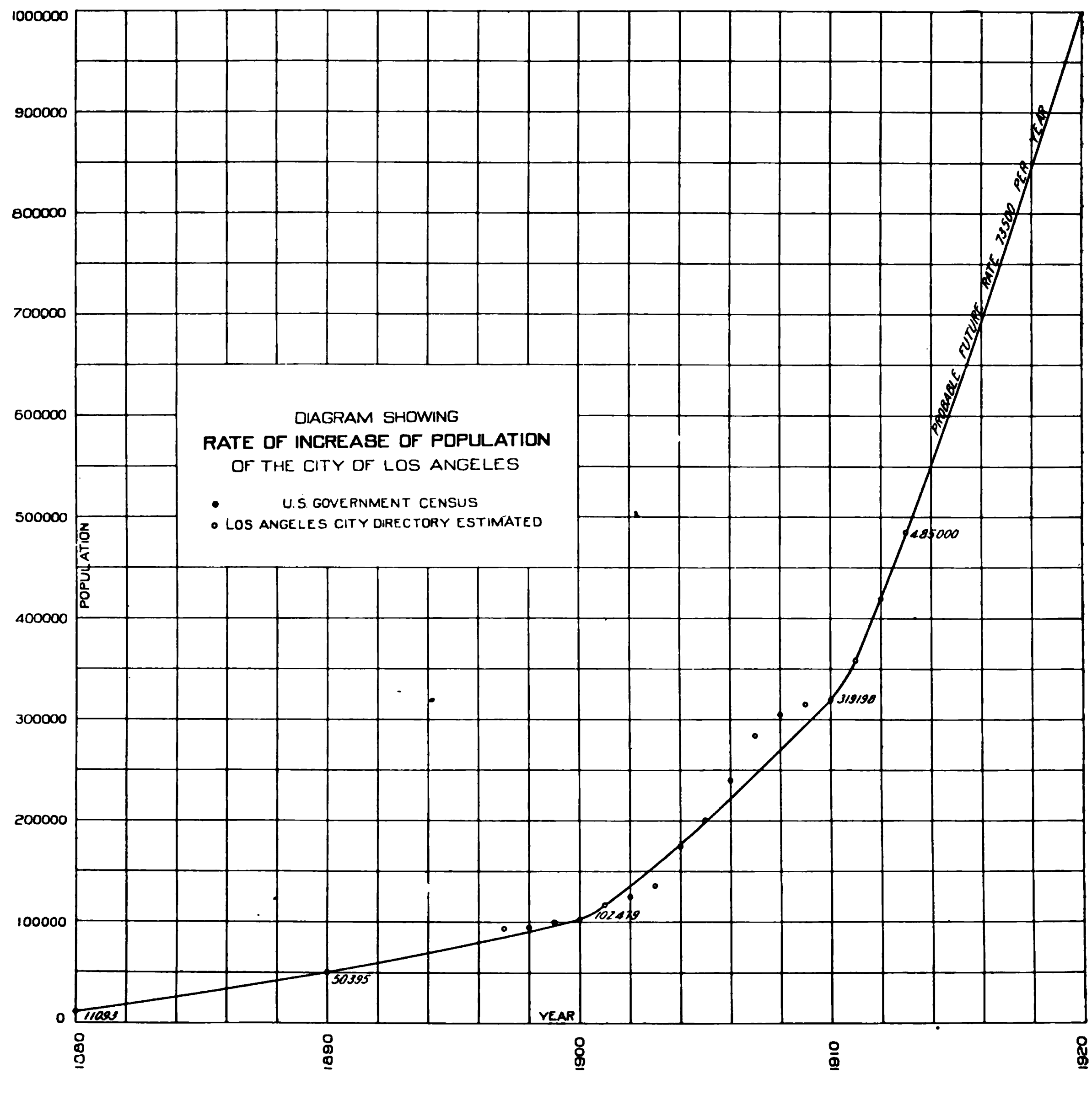
down the incline, he pointed to it and said: "There it is, take it!"

Two storm periods of abnormal severity, accompanied by rainfall of unprecedented volume, have occurred since completion of the aqueduct, yet, with the exception of a remarkable effect upon the Antelope siphon, no damage to the conduit line was done by the floods that destroyed roads and bridges and put railroads out of use for days in Southern California. The heavy rainfall and great run-off of flood water in January, 1916, caused no damage at all to the Aqueduct, and it remained in commission without an hour's interruption all through the storm.

In February, 1914, the rainfall in the Mojave desert region exceeded by nearly fifty per cent in three days the average annual precipitation. Where the steel siphon crosses Antelope valley at the point of greatest depression, an arroyo or run-off wash indicated that fifteen feet was the extreme width of the flood stream, and the pipe was carried over the wash on concrete piers set just outside the high water lines. The February rain, however, was of the sort known as a cloud-burst, and the flood widened the wash to fifty feet, carried away the concrete piers, and the pipe sagged and broke at a circular seam. The water in the pipe escaped rapidly through the break under a head of 200 feet, and the steel pipe collapsed like an emptied fire hose for nearly two miles of its length. In some places the top of the pipe was forced in by atmospheric pressure to within a few inches of the bottom. The pipe is ten feet in diameter, and the plates are 1/4 and 5/16 of an inch thick. Many engineers pronounced the collapsed pipe a total loss, and advised that it be taken apart, the plates re-rolled and the siphon rebuilt.

The damage was repaired, however, by the simple expedient of turning the water in after the break was mended, relying on the pressure to restore the pipe to circular form. The hydraulic pressure, under gradually increasing head, restored the pipe to its original shape without breaking any of the joints or shearing the rivets, and a month after the collapse the siphon was as good as new. The total cost of repairing the siphon was only $3,000. It would have cost about $250,000 to take it apart and rebuild it.

Similar accidents to steel pipe have occurred on other works, but never before has a collapsed pipe been restored to form by the simple method applied to the Antelope siphon.



This curve was developed in 1913 and was based on the then present growth. The City Directory Census of March 1, 1916, was 555,363

FINAL REPORT ON THE CONSTRUCTION OF THE LOS ANGELES AQUEDUCT

The Available Water Supply for Los Angeles in 1905

Los Angeles, founded as a Spanish pueblo in 1781, was a village of 3,700 souls in 1860, a town of 11,000 in 1880, a city of 102,000 in 1900, and a metropolis of half a million in 1913. In the region surrounding the city a dozen or more young cities and towns, increasing in population and resources with great rapidity, are connected with Los Angeles by suburban residences and small farms, aggregating in population almost that of the parent city. The assessed valuation of this city increased from $7,259,588 in 1880 to $513,971,652 in 1915.

The pueblo of Los Angeles was established by the Spanish Crown for the primary purpose of raising subsistence supplies for the small army of occupation. These Spaniards came from a country that thrived by irrigation, and they applied their methods in Mexico and California. Water was the element that determined the location of a pueblo, and the area of the grant generally was adjusted to the available supply. This was done in the case of the Pueblo of Los Angeles. A grant of one league square was made, and the Los Angeles River became appurtenant to this Pueblo by Spanish authority in 1781. The waters were diverted onto the Pueblo lands and used for agricultural purposes. The community was purely communistic. No lands were separately held until after the American occupation and the treaty of Guadalupe Hidalgo in 1848.

Rate of Use

It has been found that, under conditions of soil and climate that obtain in the region of Los Angeles, a water supply adequate for the irrigation of a given area for agricultural purposes is also sufficient for the same area when occupied as a city, such as Los Angeles, which is always in an unconsolidated form, encroaching on the surrounding country. This fact is applicable to the problem of distribution of the surplus waters which the City has obtained, and affords a measurable basis of computation of the amount of territory to be included for Aqueduct distribution.

It was not until after the city expanded beyond the bounds of the original pueblo that a shortage began to appear in the water supply. In 1911 the water system owned and operated by the City covered an area of 24,000 acres, with a consumption of 40 million gallons daily, or at the average rate of one miner's inch to 7.77 acres. This area was estimated to be about two-thirds occupied. In the business section of the City the consumption was at the rate of a miner's inch, or 0.02 c. s. f., to 5 acres, a higher rate prevailing in certain blocks occupied by office buildings and hotels. This city, with its freedom to grow in all directions, will always contain within its expanded boundaries a certain ratio of unoccupied land, which it is believed will not differ substantially from present conditions. Therefore, it is estimated that a supply at the rate of one miner's inch to 7.5 acres will be sufficient.

Water Works Franchise

In 1868 a thirty-year franchise was granted for a water works in the town; the consideration being the establishment of a fountain in the old City Plaza. This fountain still exists, consisting of a one-inch pipe, with a sprinkler attachment, surrounded by a small concrete basin.

The expiration of the franchise in 1898 was preceded by two years of agitation and followed by four years of litigation between the old water company, which sought to retain the then valuable property, and the City of Los Angeles. In February, 1902, the present municipal water works was initiated, the transfer of the property having then been made. At the time of the transfer the mains consisted mostly of riveted steel pipe, and 70 per cent of the distributing system was 2 inch screw pipe. The City retained the experienced officials from the old water company, and initiated a policy of reducing water rates and of reconstructing the system. Today Los Angeles enjoys as low a water rate as any California city; about 10 cents per thousand gallons, and two-thirds of the million dollar gross annual income from the plant is profit, which is going into betterments.

Annual Rainfall*

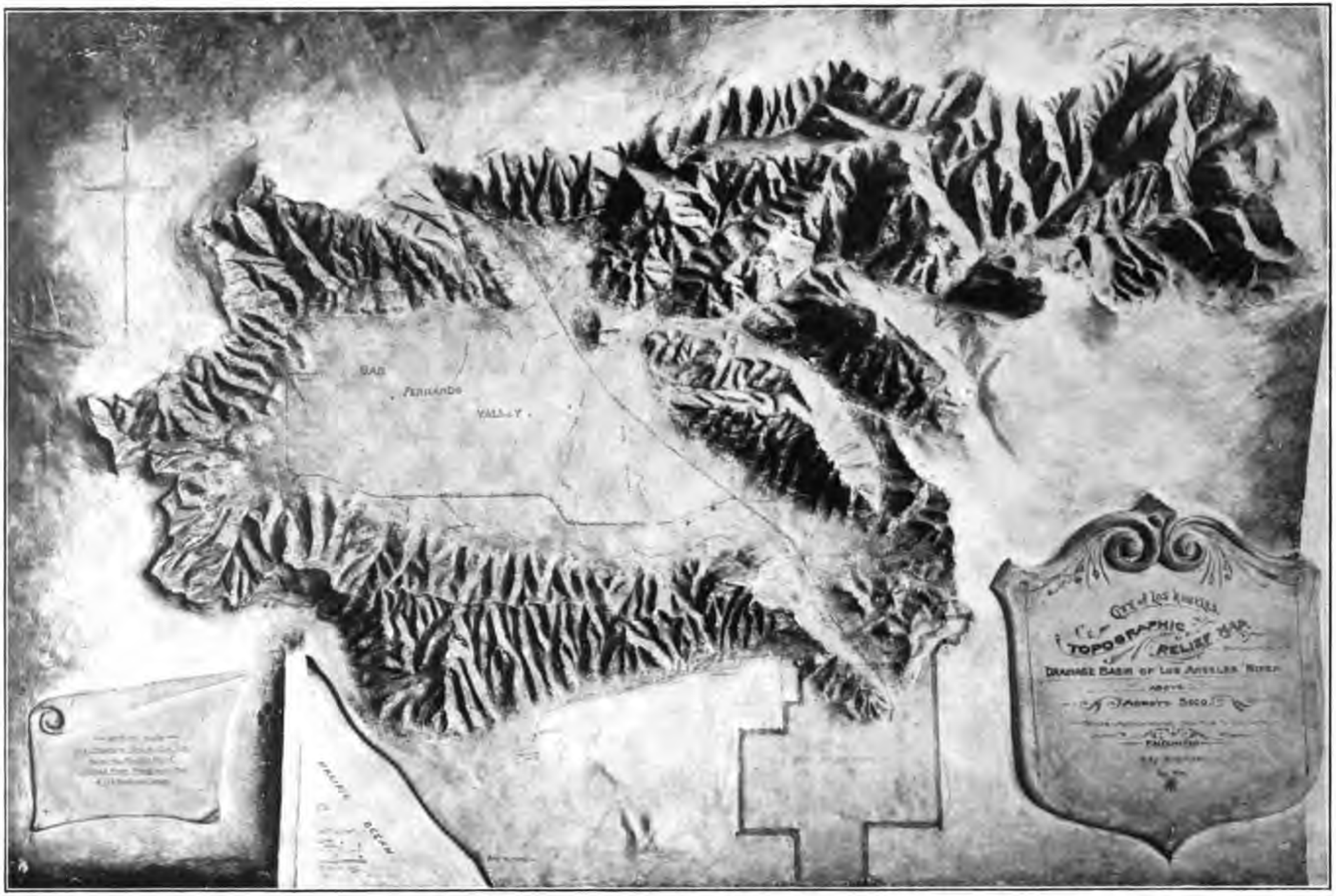
In a semi-arid region, fluctuations in the annual rainfall produce wide variations in the stream flow. The precipitation at Los Angeles averages but 15 inches, with greater amounts in the mountains. Dry years occur when the rainfall is but a third of the mean. There is little if any run-off from the mountain drainage basin until the seasonal precipitation thereon exceeds 10 inches. Consequently, when the annual rainfall drops below this amount, we are confronted with conditions of water shortage that are difficult to appreciate in eastern sections of the country. These cycles of wet and dry years occur generally in groups. The eleven seasons from 1893-4 to 1903-4 averaged but 11.25 inches, whereas the eight seasons following averaged 16.10 inches. In the case of domestic water works, the dry years are the controlling factor and the design of the system is governed by these years of drouth.

The drainage basin of the Los Angeles River above the narrows, consists of 174 square miles of high mountains, that produce practically all of the water crop; 153 square miles of low foothills and 175 square miles of the San Fernando Valley lands. The eastern third of this valley fill consists largely of sands and gravels of an absorbent nature, sloping gently towards the Cahuenga Mountains and the narrows of the river at the southeast corner of the valley. The winter floods of the Sierra Madre are discharged upon these absorbent gravels, where they rapidly sink, forming a great underground reservoir with a sloping water plane. This reservoir discharges with marked regularity through its outlet at the northern and highest part of the City, the Narrows of the Los Angeles River. Few floods, except in wet years, pass completely over the gravels through the Narrows and to the sea. A series of wet years builds up the water levels on the higher portion of this valley, and during a series of dry years this water plane gradually flattens, but the outflow is surprisingly constant. For this reason, periods of drouth do not immediately manifest themselves in the municipal water supply. While the discharge of the mountain streams, such as the San Gabriel, in a year of extreme drouth, will be less than 10 per cent of the mean, the minimum flow of the Los Angeles River at the Narrows will not be less than two-thirds of the mean.

Menace of Shortage

In 1905 the City's needs for water were such that not only the complete surface flow of the Los Angeles River was being diverted, but underground galleries in bed rock had been constructed across the Narrows of the river, so as to withdraw the subterranean flow during the summer time; and wells had been put down in the southern side of the City, which lies in the coastal plain, from which water was pumped during the summer months directly into the mains to meet the demands on the system. Another pumping plant was erected by a private water company at the Jefferson Street wells, and yet another, by the City water department, located in the gravel bed of the Los Angeles River opposite the Los Feliz Point in the northern part of the City. The total product of this entire plant in July, 1905, was 71½ cubic feet per second, or 46 million gallons daily. In July, 1905, during a 10-day

*See Plate No. 22. Rainfall and Flow of Los Angeles River—in map pocket.



MODEL OF DRAINAGE BASIN OF LOS ANGELES RIVER

hot period, ending with July 30th, the consumption reached 39,276,000 gallons daily, and the Water Department was forced to notify its patrons of an impending shortage, the domestic reservoirs having been depleted in certain sections of the City to the extent of 3½ million gallons daily. Fortunately, at this time, the temperature moderated and the warning of the Department began to have its effect to such an extent that the consumption dropped to about 33 million gallons daily. For an ambitious city, that was increasing its population at the rate of 150 per cent with each decade, and with a knowledge of the scarcity of water from other local supplies, this was a warning that could not be disregarded.

The U. S. Geological Survey gauged daily the run-off from the 222 square miles of high mountain country, rising to elevations for 10,000 feet, in the basin of the San Gabriel River, above Azusa, for a period of 16½ years, from January, 1896, to July 1st, 1912, inclusive, covering groups of wet and dry seasons. The mean flow from this basin, which adjoins that of the Los Angeles River, was .716 feet per second per square mile. If we apply this same rate of discharge to the 175 square miles of the high mountainous basin of the Los Angeles River, we would have a mean flow of 124.6 cubic feet per second, or 80.5 million gallons per day, as a total yield, and 83 second feet or 53.5 million gallons per day for a cycle of dry years. From this amount (124.6 second feet) must be deducted the pumping diversions by irrigators in the San Fernando Valley, and occasional flood discharges passing over the gravels and past the City. The safe yield from the basin of the Los Angeles River during the dry or controlling years was estimated at not over 45 million gallons daily.

Flow of Los Angeles River

A Board of Engineers, consisting of J. H. Quinton, W. H. Code and Homer Hamlin, all members of the American Society of Civil Engineers, in a report on the distribution of the surplus waters of the Los Angeles Aqueduct, in 1911, placed the available water supply from the surface streams and pumped water from the underflow of the Los Angeles River, at 80 cubic feet per second (51.7 million gallons per day), this being the average supply and not a dry year supply. On August 16, 1912, the consumption of the City was 63.2 million gallons. It is estimated that the City at present has a population of 550,000 souls, with a per capita consumption, two-thirds of which is metered, of 140 gallons per day in mid-summer. Because of the occurrence of a series of years above normal precipitation during the period of Aqueduct construction, it was possible to avert serious water famine.

Ground-water Subsidence

In addition to practically complete diversion of the surface stream, there was steady subsidence of the underground water supply. One mile south of the City, the water in a well that was put down by Mr. J. S. Slauson dropped 29 feet in 12 years, and at the City's pumping plant on Slauson Avenue, in 4 years, the water dropped 9 feet. In the coastal region, southerly from the City, a large artesian area shrunk one-third in size, and the wells that continued flowing discharged diminished amounts. These wells are all in a broad gravel bed, which is supplied with water from a common source.

Conferences were held in 1903 and 1904 by leading citizens, interested in the prosperity of the City and in the water works, to consider this situation. At that time no solution was suggested. Therefore the city officials were not only justified in taking up the study of a new water supply for this community, but it was a matter of dire necessity, involving restriction of the City's growth in case a remedy could not be found. The Federal Government detailed engineers and geologists from the Geological Survey to study the water problem of this region, and their reports were uniformly to the effect that further encroachments on underground supplies were hazardous.* Manifestly, more water could not be taken continuously out of these gravel beds than would be contributed to them during average years.

(*) U. S. G. S. Water Supply Papers Nos. 137, 138, 139 and 219.

Rights to Underground Flow

As intensive and profitable agriculture, in this region, is dependent upon the available water supply, and as lands without water have intrinsic values less than one-fourth of those having water, it naturally followed that private parties made encroachments at every possible point upon the water supply of the City. Men on the small farms in the San Fernando Valley, overlying the underground waters of the Los Angeles River, put down wells upon their own lands and pumped therefrom and applied the waters on the lands which they owned. The City was obliged, in order to provide for the necessities of its citizens, to procure injunctions against these intrusions, but enforcement of the orders of the court would be so disastrous to those who had built small homes that it was deemed inexpedient to apply them unless actual water shortage should make such action imperatively necessary, although the City had spent $150,000 in establishing its rights to this water.

Investigation of Other Sources of Supply

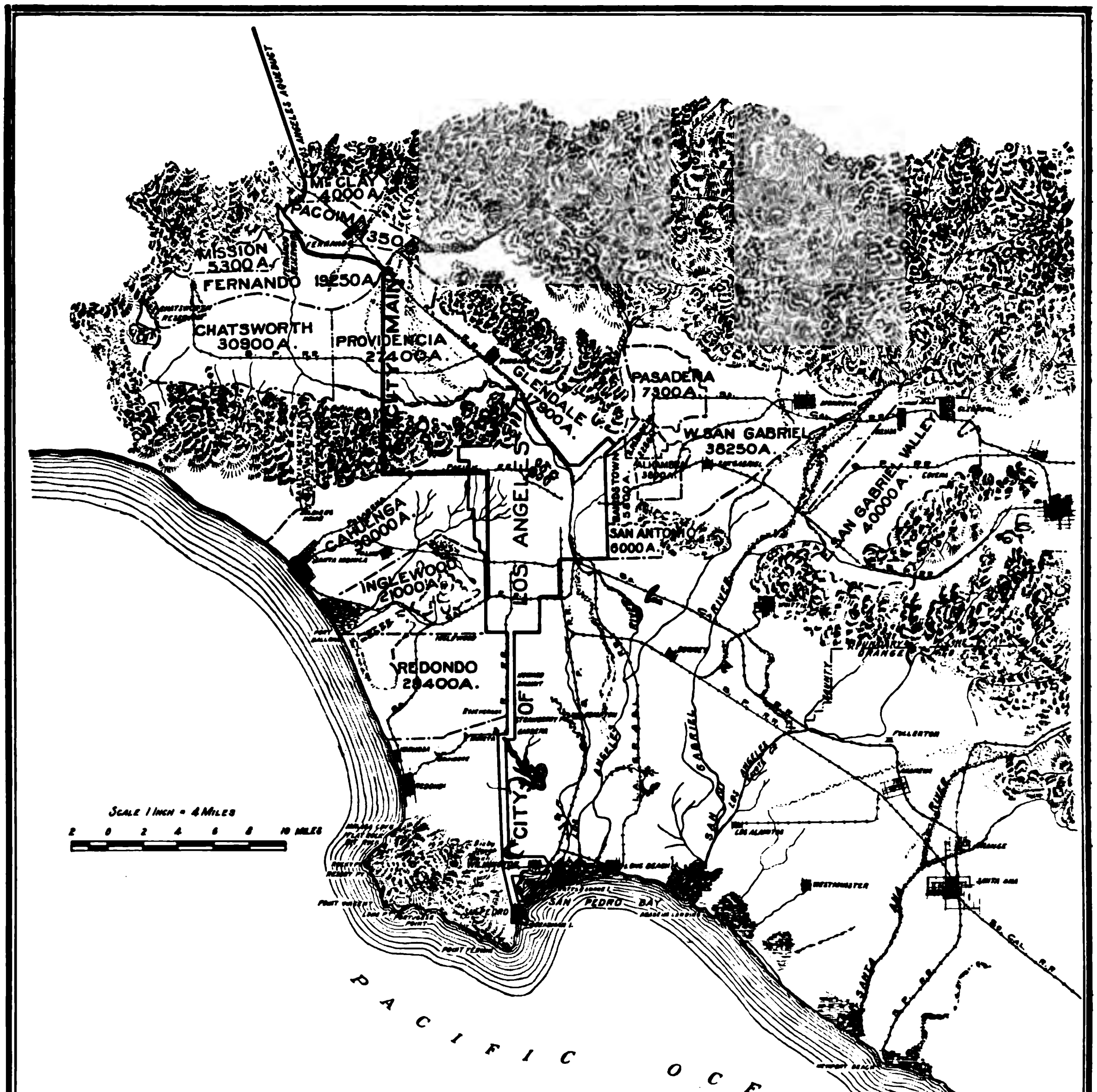
In co-operation with Mr. Wm. Mulholland, Superintendent of the Water Department, Mr. J. B. Lippincott, who had been in charge of the investigations of the available water supply in the State of California for the Hydrographic branch of the U. S. Geological Survey for a period of ten years, and who was at that time Supervising Engineer in the U. S. Reclamation Service, was employed to make a study and a public report on all the possible sources of water supply in Southern California. An extensive investigation was made of all the local water supplies, both surface and underground, extending from the Malibu Ranch to the Mojave River. The result of these investigations was published as a portion of the Fourth Annual Report of the Water Commissioners, for the year ending November 30, 1905.

Big Tejunga

Among the sources considered was the possibility of storing water on the Big Tejunga, which is the principal tributary of the Los Angeles River. This stream rises in the high mountains at the eastern edge of the drainage basin and flows through mountain canyons, with steep grades, to the San Fernando Valley, where it is discharged onto the gravel beds and rapidly absorbed, in this manner supplying the underground reservoir, which feeds the Los Angeles River. Except in years of unusual rainfall, there are no floods which completely pass over these gravels and discharge through the Narrows into the river and past the City. Consequently, any storage in the canyon, particularly in the dry controlling years, would result in a direct depletion of the Los Angeles River and of the City's supply therefrom.

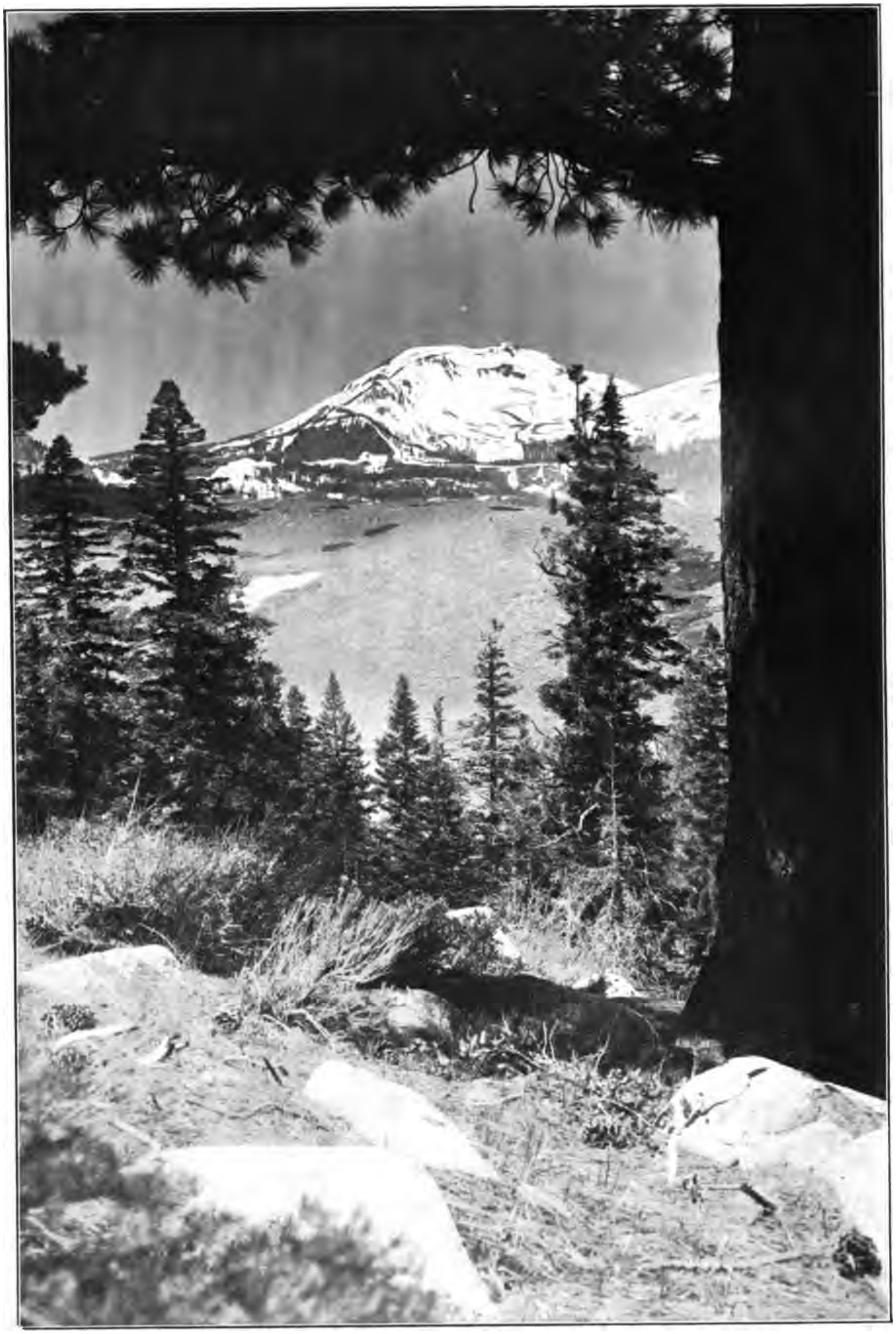
Mojave River

One source of water supply which had been suggested was the Mojave River. A large reservoir site exists near the town of Victor, but it is so flat and shallow, and the water supply for it is of such an uncertain nature in dry years, that it was estimated that not over 60 second feet could be relied upon. This amount was not sufficient to afford permanent relief. On the high mountain tributaries of this stream, reservoir sites had been located and partly developed to store irrigating water for portions of the San Bernardino Valley. Possibly these works could have been purchased and a moderate supply of water obtained for the City from this source, but it would only have been after condemning expensive riparian rights on the lower portion of the stream and checking the agricultural development of the San Bernandino Valley, which is commercially tributary to the City of Los Angeles.



MAP SHOWING DISTRICTS ON WHICH OWENS RIVER WATER MAY BE DISTRIBUTED

INSTALLATION OF MAINS IN NORTHWEST DISTRICTS IS NOW IN PROGRESS



THE HIGH SIERRA IN SUMMER

area irrigated is 15,760 acres; the total amount of undeveloped underground water is between 40 and 50 second-feet; the original area of artesian lands is 28.4 square miles; the present (1904) artesian area is 8.7 square miles; and the total lowland area, much of which is not cultivated, is about 250 square miles. A part of the City of Los Angeles covers more than 22 square miles of this area, and the growing towns of Santa Monica, Ocean Park, Hollywood, Inglewood, Redondo, etc., occupy many more miles of it.

"Although the quantity of water developed and the acreage irrigated by it are thus seen to be moderate, the local water supply is not controlled entirely by developments within the district considered, but is affected more or less by developments and diversions in adjacent regions. The shrinkage in that part of the coastal plain artesian basin which is included in the Redondo and Santa Monica quadrangles, for instance, in so far as it is not due to drought, is probably due more to the complete diversion of Los Angeles River waters and to developments in the artesian basin farther east than to direct attacks on the ground waters in the areas in question.

"The total number of flowing wells in the entire coastal plain artesian basin in 1904 was 2,500, and their yield is estimated at not less than 300 second-feet. The effect of this great drain, in conjunction with the past decade of dry years, has been to reduce the artesian area from about 290 to 190 square miles, the shrinkage taking place principally along the northern and northeastern borders of the basin, which first show the effects of a decrease in supply, for the same reason that water withdraws faster from the shallow upper end of a draining reservoir than from the lower deeper end. Hence in the Santa Monica and Redondo quadrangles, the original area of 23 square miles is now reduced to 3.5 square miles.

"The small Ballona district, in which there are but four or five flowing wells, has not had serious drafts made upon it. Its situation, and the drainage tributary to it, should make it fairly resistant to reasonable drafts. The flowing wells about Colegrove are in deep-lying sandstones of Tertiary age and their life is difficult to estimate.

"The quality of these waters is not such as to invite their further exploitation so long as purer waters are obtainable."

Artesian Shrinkage

This quotation relates to the districts immediately west and south of the City, on which a portion of the water from Owens River may be placed. The coastal plain is that broad area extending between the City of Los Angeles, the Puente Hills and the sea. In this area many wells and pumping plants have been established. In 1904, Mr. Mendenhall estimated that $2,413,000 had been invested in these plants; that their output amounted to 275 second-feet, or 13,750 miner's inches, and that 100,000 acres were being irrigated therefrom. Mr. William Hammond Hall, State Engineer of California, in 1888 estimated that the area of land from which artesian water could be obtained in this district, was 296 square miles. Mr. Mendenhall, in 1904, found that it had shrunk to 192 square miles, and that the flow of the wells within the area remaining artesian had materially diminished.

All these studies and opinions regarding the underground waters of the Coastal Plain agreed that in case the City endeavored to obtain an adequate supply for its future requirements from this source, it would have to enter into a contest with all the interests that have become vested in this district, and such a conflict would, if successful, reduce greatly the water supply for a large area tributary to the City.

San Gabriel River

The San Gabriel River is the next stream easterly from the Los Angeles River. The mountainous portion of its basin, above Azusa, drains 222 square miles. Its winter floods are discharged onto the gravels of the San Gabriel Valley, and reappear in a surface flow and in saturated gravels in the Narrows near Puente. All the ordinary summer flow and some of the winter flow in ordinary years, and all of it during dry years, is diverted for irrigation

uses around Duarte, Azusa and Covina. The underground waters appearing in the lower narrows near Puente are diverted for use near Whittier, Downey and Norwalk, towns suburban to the City of Los Angeles. In 1898 the winter flow from the upper San Gabriel basin passing the upper irrigation canals amounted to but 125 inches, and for the year 1909 there was practically no surplus whatever. In wet years this surplus is material, but it is the dry years that govern, especially in a domestic water supply. Above the lower narrows there is a drainage of 321 square miles of high mountains, which, on average years would discharge about 229 second-feet upon the gravels. Probably two-thirds of this water, or 153 second-feet, would be absorbed by the gravels. In 1905 there were 49 pumping plants in or above the narrows of the lower San Gabriel River, with an estimated pumping capacity of 3,096 miner's inches.* In addition to this there were 13 small canals diverting this water and irrigating 17,528 acres. All of the surface flow is ordinarily so diverted.

The elevation of these water-bearing lands is about 200 feet above sea level, and they lie about 15 miles distant from the City of Los Angeles. The average elevation of the City of Los Angeles is between 250 and 300 feet, and the maximum is more than 700 feet. It was estimated that the cost of delivering this water, by means of pumps, under proper pressure, for municipal service, would have been 3.6 cents per thousand gallons, including indefinite charges for condemnation and legal expenses. This is more than the cost of delivering water to the City from the Owens River. Moreover, taking this water for the City would decrease the supply that is necessary for the irrigation of territory commercially tributary to Los Angeles.

*Water Commissioners' Report for year ending June 30, 1905, p. 40.

Economic Factors

The conclusion drawn from hydrographic studies was that, with the exception of flood discharges in wet years, all of the stream flow in Southern California was being utilized. If the City of Los Angeles should exercise the right of eminent domain and condemn the local irrigation waters for a superior domestic use, it would not only work great injury to the farming interests, but would virtually ruin towns and highly developed communities.

In 1905-1906, the districts of Corona, Ontario, Redlands, Riverside and San Diego were irrigating 68,000 acres of land. The gross crop value for that season was estimated at $22,225,000. Lands near Riverside, before being supplied with water, were valued at $18.30 per acre and used as sheep pasture. After orchards had been developed upon them by irrigation, their value became $1,000 per acre and more, and the 68,000 acres above referred to were supporting 39,000 people on the irrigated lands. Riverside, with 20,000 acres irrigated, had 16,000 acres in citrus fruits, of which 2,000 acres were young trees, and the crop value for the season of 1905-1906 was estimated at $8,400,000, or $3,000,000 net to the growers. The total crop value for Riverside's 20,000 acres, including citrus fruits and forage crops, was estimated at $9,600,000 gross, or $480 per acre. Its population was 12,500; its assessed valuation was $8,500,000 and the bank deposits were $3,000,000.

Consideration of all the factors in the problem led to the conclusion that the right economic policy of the City of Los Angeles was to obtain and deliver a new supply as large as it could possibly obtain and pay for, and to use this water not only for the immediate domestic requirements of the City, but for the upbuilding of tributary suburban country.

MAMMOTH CREEK, ONE OF THE SOURCES OF OWENS RIVER

INCEPTION OF THE AQUEDUCT PROJECT

The idea of bringing the water of Owens River to the City of Los Angeles originated in 1893 with Mr. Fred Eaton while he was engaged in ranching in Owens Valley. Mr. Eaton had been for several years Engineer and Superintendent of the Los Angeles City Water Company, was subsequently City Engineer, and was Mayor of Los Angeles during the years 1899-1900. His training as an engineer, both for the City and the old water company, together with his general knowledge of the water situation in and around the City of Los Angeles, particularly qualified him to judge intelligently of the merits of this project.

In the fall of 1904 Mr. Eaton, on his own responsibility, began quietly obtaining extensive contracts and options on water-bearing property in the southern portion of Owens Valley. He expended over $30,000 of his own on these contracts, which never was refunded by the City. With these in hand, he first presented the matter to representatives of the City of Los Angeles late in the fall of 1904. Mr. Eaton's original proposition contemplated a combined private and municipal project, the City to receive 10,000 miner's inches of water for domestic uses and the surplus water to be available for Mr. Eaton and his associates for disposal outside the City. He proposed that this surplus water should pay toll for its transmission through the Aqueduct. The Aqueduct was to be built and paid for by the City and have a capacity of 20,000 inches. Under the terms of this proposal, Mr. Eaton was to secure all necessary lands and water rights, and to deliver the water without cost to the City. Mr. Eaton made other proposals, including one that provided for his purchase of necessary water rights, the City to build the Aqueduct and own all the water, but Mr. Eaton to retain the right to develop and own all the water power incident to the construction.

Municipal Ownership

The Board of Water Commissioners declined these offers, and insisted upon exclusive municipal ownership and control.

At this time the United States Reclamation Service was investigating the Owens Valley project and had withdrawn from entry large areas of public lands there, including reservoir sites, and had filed on the water. Mr. Eaton's program was presented to the officials of the Reclamation Service, including Mr. F. H. Newell, Chief Engineer, and Mr. J. B. Lippincott, Supervising Engineer, for the first time in the fall of 1904. Both these officers of the Reclamation Service took the stand that they could not aid the City of Los Angeles unless the project was exclusively municipal.

Preliminary Survey and Estimate

The Board of Water Commissioners detailed their superintendent, Mr. Wm. Mulholland, to make an investigation of the water supply in Owens Valley in September, 1904. This was followed by a careful reconnaisance of the route on the part of Mr. Mulholland to determine the practicability of the construction of the conduit to bring the water to the City of Los Angeles. About three months were spent on this reconnaisance work. The Superintendent reported favorably on the adequacy of the water supply and the feasibility of constructing an aqueduct to bring it to the City, and made a preliminary estimate of the cost of such an enterprise, which he placed at $23,000,000 for construction work alone.

In April, 1905, Mr. John J. Fay, Jr., President of the Board, J. M. Elliott and General M. H. Sherman, all Water Commissioners, accompanied by Mayor McAleer, City Attorney Mathews, and Messrs. Eaton and Mulholland, made a visit to the Owens River Valley for the purpose of further inspecting the project and for considering Mr. Eaton's proposals. After carefully considering all available infor-

mation concerning sources of water supply sufficient for the needs of the City, the Board became convinced that the Owens River afforded the only adequate supply that could be obtained by the City at a cost which it would be justified in incurring.

Proposal Accepted

Having reached this conclusion, the Board entered into a contract with Mr. Eaton on May 22, 1905, for the acquisition of the property embraced in the proposal submitted by him, and the Board used the available public funds of the Water Department to the extent of $233,865 for that purpose. Appendix "B" of the First Annual Report of the Aqueduct gives the official minutes of these proceedings. The Board thus acquired 22,670 acres, together with all water rights appurtenant thereto, including 16 miles of frontage on the Owens River, also an easement permitting the use perpetually of 2,680 acres in the Long Valley reservoir site, below the 100-foot contour, for storage purposes, and in addition thereto options held by Mr. Eaton on large tracts of land with extensive frontages on the Owens River below what is known as the Rickey property. The commercial organizations of the City were taken into full confidence of the Water Commissioners at each step, and this program was fully concurred in by them. Mr. Eaton reserved for himself the live stock on the ranches that were bought, 640 acres of farm land in Owens Valley for a home place, and certain lands in Long Valley, above the 100-foot contour of the reservoir, for a mountain pasture.

As Mr. Eaton controlled the situation, the results obtained were favorable to the City and only just to him. He acted in a public spirited and generous manner toward the City. Subsequently, he continued for a short time to purchase lands for the City in Owens Valley and was paid for these latter transactions a commission of 5 per cent on what he then purchased and $10.00 per day for expenses.

When municipalities or large corporations attempt to buy properties for a public necessity, the tendency is for land owners to inflate values with a view to obtaining the maximum possible prices, due to the public necessity. Any advance knowledge of the intentions of the City of Los Angeles to purchase great tracts of land and water rights in Owens Valley would certainly have led to local excitement and loss to the City. The City officials, therefore, conducted preliminary negotiations in this quiet and business-like manner, before making public announcements.

Project Approved

When the City's position became reasonably secure, the minutes and correspondence of the Board of Water Commissioners were made public and the City was asked to vote one and one-half million dollars in bonds for the completion of the payments and for making the needed additional investigations. The City of Los Angeles thereupon endorsed the actions of the Water Board by the record vote of 14 to 1.

MT. MORRISON FROM CONVICT MEADOWS

WATER SUPPLY OF OWENS VALLEY

The Owens Valley lies between the easterly base of the Sierra Nevada mountains and the Inyo Range. The valley is about 120 miles in length and ranges from 6 to 12 miles in width, and lies at an elevation of between 3,500 and 6,500 feet. It is situated partly in Inyo and partly in Mono counties, and is approximately in the central portion of California, north and south, and on the desert side of the range. It is isolated from the San Joaquin Valley and San Francisco Bay points by the high Sierras, the passes across which are approximately 10,000 feet in elevation.* The Mojave Desert and the Coast Range intervene between it and Southern California.

The waters of Owens River rise on the high peaks of the Sierra Nevadas. There are 40 crests that attain an elevation of over 13,000 feet along the westerly side of this basin, the highest of which is Mt. Whitney, with an altitude of 14,501 feet, which is the highest peak in the United States proper. These waters drain into Owens Lake, which has an elevation of 3,567 feet, an area of 100 square miles, and no outlet. It is consequently saline. The rainfall on the floor of the valley is but 5 inches, and the total area of the basin tributary to the lake is 2,810 square miles. The evaporation losses from this lake are as great as the amount of water which the City proposed to divert into the Aqueduct.

The floor of the drainage basin of Owens River, north of Bishop, is composed to a great extent of volcanic ash and of volcanic and tufaceous rocks, all of which are absorbent of water and which tend to regulate the outflow. In addition the canyons that have been carved out of the granite face of the sierra have discharged great gravel cones, which are also absorbent of surface waters and which liberate them through their outlets in a regulated flow. This has a marked physical effect on the regimen of the main river.

*See Plate No. 1. Geological Section Owens Valley—in map pocket.

Flow of Owens River

The Owens River has been gauged at a point known as Round Valley, by the U. S. Reclamation Service and later by the City of Los Angeles, since 1903. The year 1907-9 represents about average conditions of flow, so far as observed. The minimum flow of the river during that year was 191 second-feet, the maximum 441 second-feet, and the mean 260 second-feet, the ratio of the minimum to the mean being 2 to 3. The Kings River, immediately over the divide, was also gauged by the Geological Survey at the mouth of its canyon. This stream is not subject to the regulation afforded by the retarding effect of fragmental material, as in the case of the Owens River. During the year 1907-8 the maximum discharge of Kings River was 6,920 second-feet and the minimum 265 second-feet, the ratio being 31 to 1. For the entire period 1903 to 1912 inclusive, the minimum flow of Owens River at Round Valley was 121 second-feet and the maximum 1,190 second-feet, the ratio being 10 to 1, while on Kings River, during the same period, the maximum was 26,600 second-feet and the minimum 130 second-feet, or a ratio of 204 to 1.

There is another gauging station on Owens River at Charlie's Butte. This is near the point of diversion of the Aqueduct and below the numerous irrigation diversions in the upper portion of the valley. The records began at Charlie's Butte in 1906. During a period of eight years the maximum flow at this station was 2,610 second-feet and the minimum 36 second-feet, the ratio being 72 to 1. This minimum condition, however, is abnormal and artificially affected by irrigation uses above. From the above data it will be noted that the Owens River is a stream of marked constancy of flow, which increases its value as a source of water supply, and furthermore that it is likely to be misleading to make comparisons for wet and dry years between Owens River

records and the longer records of streams on the opposite side of the sierra. The regimen of the Owens River resembles more nearly the conditions of the flow of the Los Angeles River at the Narrows, or the Santa Ana River at its lower narrows at Rincon.

Evaporation Records

Mr. Charles H. Lee, for a period of three years, studied the hydrography of Owens Valley jointly for the City of Los Angeles and the U. S. Geological Survey. Extensive original research work was accomplished. The results are given in Mr. Lee's report, a synopsis of which is published herewith as Appendix "A."

Lands and Water Rights

The lands and canals purchased by the City in Owens Valley were bought for the purpose of controlling the riparian rights on the Owens River and thus protecting the City against legal injunctions or adverse diversions, and in many instances for the direct purpose of buying the water rights of small streams, ditches and springs. The lands were also bought with the view of controlling artesian waters of the valley.

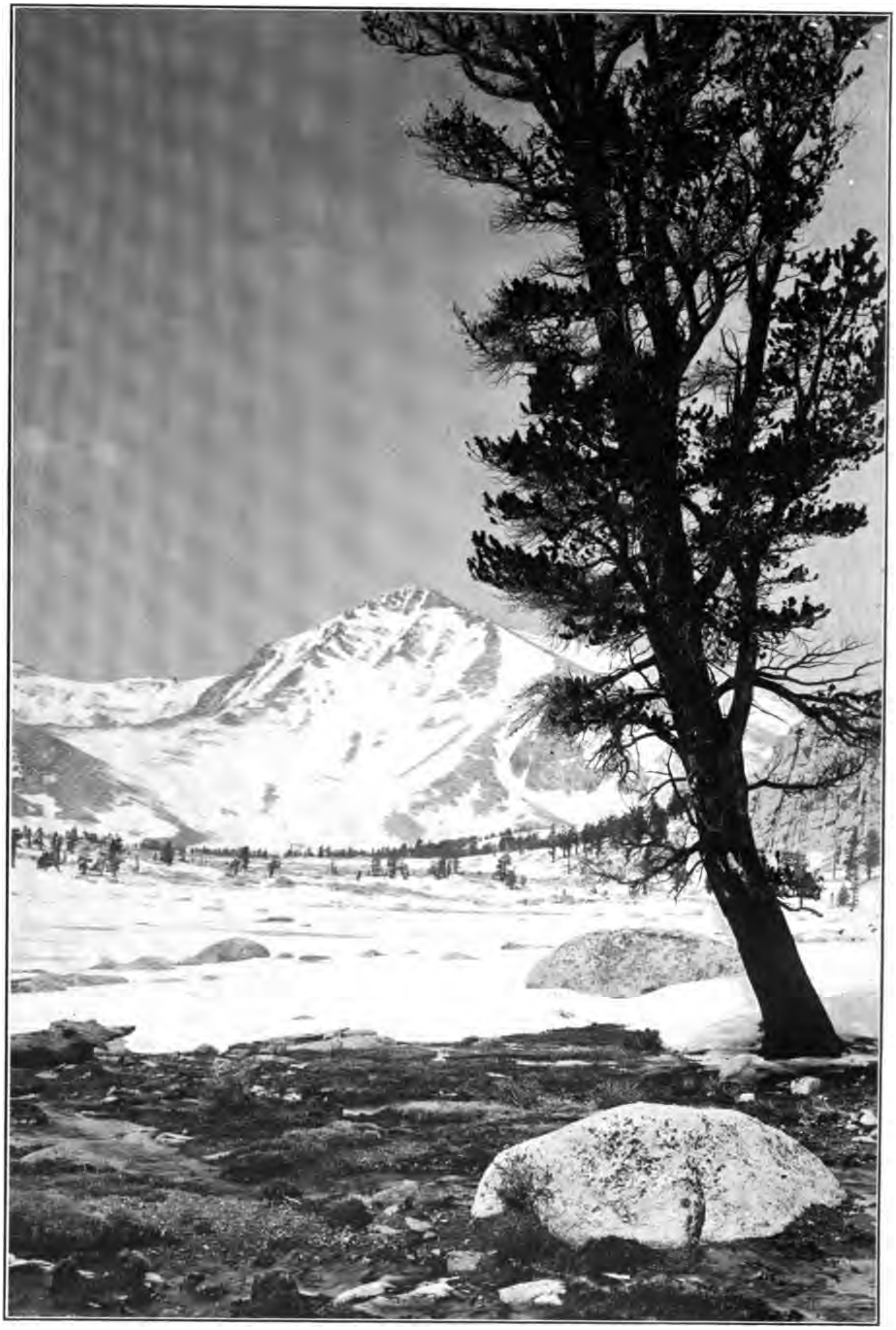
These waters may continue to be used for irrigation in Owens Valley until they are required by the City, and the City is leasing these lands for farming purposes and permitting of this irrigation use.

FOLLOWING TABLE GIVES A LIST OF THESE CANALS

Estimate by Fred Eaton of the normal flow of small streams, ditches and springs purchased by the City in Owens Valley.

Name	Normal Flow
Haiwee Canyon and Springs	50 miner's inches
Ed. Walker Creek	75 miner's inches
Ash Creek	100 miner's inches
Cottonwood Creek	1000 miner's inches
Lone Pine Creek (water rights of Boland Estate) (First right 600 in., surplus rights.)	150 miner's inches
Hogback Creek	100 miner's inches
The lands which control about one-half of surplus waters of George's Creek	Undetermined
Lands controlling portion of surplus of Shepard's Creek (25 miner's inches in first right.)	Undetermined
Lands controlling surplus waters of Simms Creek	Undetermined
Lands controlling all the surplus waters of Independence Creek, equivalent to	300 miner's inches mean flow
Lands controlling ¾ of the surplus waters of Oak Creek	250 miner's inches mean flow
1/7 of the first water rights in Oak Creek	120 miner's inches
All Tebault Creek	50 miner's inches
Lands controlling surplus waters of Mill Creek	Undetermined

Name	Normal Flow
Black Rock Springs	1000 miner's inches constant flow
Division Creek	300 miner's inches
Little Black Rock Springs	100 miner's inches
Taboose Creek	200 miner's inches
Tibbitt's Creek	200 miner's inches
Charlie's Butte Springs	300 miner's inches constant flow
Fish Springs	750 miner's inches
⅓ of Tinemaha Creek	250 miner's inches
Lands controlling surplus waters of Tinemaha Creek	250 miner's inches
4480 out of 4500 shares in the New Stevens Ditch, which has a capacity of	2000 miner's inches
All of Herb Mulholland Ditch	500 miner's inches
½ of Settlers' Ditch, cap. 500	250 miner's inches
Wm. Penn or East Side Canal	5000 miner's inches
¾ interest in the Last Chance Ditch, which has a surplus water right from Owens River of 500 inches	375 miner's inches
835 shares out of 3,000 in the Dell Ditch, amounting to	835 miner's inches
Collins Ditch	2000 miner's inches
Collins Warm Springs (Part interest)	75 miner's inches



COTTONWOOD LAKE BASIN

Month	Discharge in Second Feet Maximum	Minimum	Mean	Run-off (total in Acre Ft.)
December	607	494	527	32,400
January	619	500	539	33,100
February	744	513	584	33,600
March	702	274	485	29,800
April	255	66	145	8,630
May	66	56	58.1	3,570
June	89	36	56.9	3,390
July	304	89	188	11,600
August	605	102	274	16,800
September	264	77	173	10,300
The Year	744	36	336	243,000
1908-9				
October	390	227	298	18,300
November	413	390	397	23,600
December	474	346	409	25,100
January	912	408	608	37,400
February	748	451	541	30,000
March	451	356	396	24,300
April	430	121	311	18,500
May	270	83	144	8,850
June	1,520	279	910	54,100
July	1,680	484	958	59,500
August	440	219	286	17,600
September	315	195	214	12,700
The Year	1,680	83	457	330,000
1909-10				
October	356	211	311	19,100
November	550	356	437	26,000
December	800	419	522	32,100
January	1,320	547	650	40,000
February	524	458	494	27,400
March	606	334	503	30,900
April	324	95	160	9,520
May	502	110	250	15,400
June	630	241	424	25,200
July	513	155	269	16,500
August	250	82	139	8,550
September	125	88	106	6,310
The Year	1,320	82	355	257,000
1910-11				
October	384	125	286	17,600
November	436	384	415	24,700
December	491	436	464	28,500
January	1,100	400	498	30,600
February	1,540	460	661	36,700
March	1,260	490	636	39,100
April	785	179	509	30,300
May	315	152	194	11,900
June	1,560	334	920	54,700
July	2,000	1,100	1,630	100,000
August	995	311	544	33,400
September	362	215	253	15,100
The Year	2,000	125	584	423,000
1911-12				
October	470	410	429	26,400
November	510	470	486	28,900
December	490	436	464	28,500
January	517	428	474	29,100
February	450	329	405	23,4[illegible]
March	347	277	316	19,400
April	329	137	255	15,200
May	228	98	160	9,840
June	517	176	333	19,800
July	325	111	153	9,405
August	106	84	89	5,459
September	96	85	89	5,276
The Year	517	84	305	220,68[illegible]
1912-13				
October	357	99	293	18,053
November	436	357	411	24,474
December	441	393	415	25,513
January	498	350	405	24,89[illegible]
February	548	390	481	26,733
March	553	350	447	27,478
April	434	67	167	9,951
May	132	63	71	4,405

NOTE—Estimates of monthly discharge for 1905 are only approximate. Part of the year the station was inaccessible, and daily discharge was determined by interpolating between measurements made at the station and at Citrus. After September the discharge was determined from the rating table.

Discharges after June, 1912, are computed from measurements made by the City of Los Angeles.

Total Water Crop

The flow which crosses the Aqueduct between the intake and the Haiwee reservoir was first platted and is summarized in seven items as follows:

Item 1.—Black Rock Springs—23 second-feet.

Item 2.—One-seventh the flow of Oak Creek at U. S. G. S. gauging station, when less than 36 second-feet and 3 second-feet when greater; minus 50% seepage and evaporation loss.

Item 3.—Flood and waste waters from the following:

horizontal indicating the fixed rate of withdrawal of 422 second-feet. When the inclination of the irregular line, or line of supply, is greater than that of the draft line, it indicates that the rate of inflow is greater than the draft. When the line of supply rises above the draft line it indicates the reservoir is being filled, or if the reservoir is already full, that water is being wasted. When the inclination of the line of supply is not so great as that of the draft line, it indicates that the withdrawals are in excess of the inflow, and as the line of supply drops below the draft line, the reservoir is being depleted. When the vertical ordinate between these lines, below the draft line, is greater than the capacity of the reservoir, to scale, it indicates a deficiency in the supply.

COTTONWOOD CREEK

QUALITY OF OWENS RIVER WATER

There was much discussion of the quality of the water from Owens River on the part of those who were opposed to the entire project of building the Aqueduct. At the very outset of the investigations, samples of the water were taken by the officials of the City. The results of the analyses of these samples could be multiplied indefinitely. They all indicate the same general result.

A special committee of the Chamber of Commerce of the City of Los Angeles was appointed in the summer of 1905 to investigate the plan of the Board of Water Commissioners for bringing a supply of water from Owens River to Los Angeles. They went into the consideration of the cost, quantities of water available and its quality. They took samples of the water and reported to the Chamber of Commerce on September 1st, 1905, among other things, as follows: "There is an ample supply for our needs and the quality of the water is satisfactory." This report was signed by W. J. Washburn, Willis H. Booth, A. B. Cass, Wm. D. Stephens, Jacob Baruch and Fred A. Hines.

Engineers' and Chemist's Reports

The Board of Consulting Engineers was instructed specifically to investigate the quality of the water at the proposed point of intake. This Board consisted of Frederick P. Stearns, one of the highest authorities on questions involving the quality of domestic water supplies in the United States, and Chief Engineer of the Metropolitan Water District, which supplies the City of Boston and surrounding towns; Mr. John R. Freeman, Consulting Engineer for the City of New York and many other large cities of the United States; Mr. James D. Schuyler, of Los Angeles, who had as much experience in hydraulic work as any other engineer in Western America. All three of these men were consulting engineers on the Panama Canal. They selected their own samples and their own chemist, Laird J. Stabler, of Los Angeles, and he reported that "This is good water for domestic purposes. The alkali forming salts are small and consequently it is good for irrigating purposes. The lime and magnesia salts are present in small quantities. This fact shows the water would not form a bad scale if used in boilers. The water would be fairly soft for laundry purposes."

The Board of Consulting Engineers stated over their signatures in their report as follows:

"We have been furnished with many additional analyses showing the quality of the water of the Owens River and its tributaries, and of the water now supplied to the City of Los Angeles. A comparison of these shows that the Owens River water is much softer than the water now supplied to the City, which contains from two to three times as much dissolved mineral matter as the water of Owens River. Our examination of the streams in the Owens Valley showed that the creeks coming from the Sierras furnished water which is clear, colorless and attractive; the water in the river being made up of the combined flow of these creeks is of similar character, but has a slight turbidity and stain owing apparently to drainage from the marshes in Long Valley and to other return water from the canals and irrigated lands. This feature would make the water somewhat objectionable if it were to flow directly from the river into the City pipes; and it has little or no significance in the present instance, where the water, after being taken from the river, is to be held for a long time in a large storage reservoir, where the particles which produce the turbidity will have time to settle. The long period of storage in the reservoir will also be an important safeguard against the transmission of disease germs, should any enter the water of the river, because it has been found both by experiment

and experience that disease germs are all or nearly all destroyed, where the water is held sufficiently long in reservoirs.

"Although the storage of water in a reservoir has a favorable effect in the directions indicated, it sometimes promotes the growth of water plants or algæ, which make the water less palatable and attractive; these growths are liable to occur with any water, and have very little, if any, sanitary significance. It is not feasible to prevent them, but it is feasible to remove their effects by aeration and filtration.

"There is an abundance of surplus fall available for aeration below the Haiwee reservoir and in the San Francisquito Canyon, where the water will either flow for several miles down the natural bed of the stream, or be discharged with great force against impulse wheels, in either case receiving most thorough aeration.

"In our opinion, water which has thus been stored and subsequently aerated, will be of better quality at its exit from the Aqueduct into the San Fernando Valley, than when taken from the Owens River."

It would seem that this statement from men of this eminence in the engineering profession would be conclusive.

Anaylsis of Samples

The U. S. Geological Survey maintains an organization that devotes its entire time to the study of the quality of the surface waters of the United States. They maintain laboratories at the University of California at Berkeley. These chemists took their own samples of the waters of the Owens River itself at the proposed intake at Charlie's Butte. The samples were collected by their agents daily, beginning in December, 1907, and extending to December, 1908, inclusive. The samples were shipped to the Berkeley laboratory. The average of all the samples taken indicates:

Silica (SiO_2)	43	parts per million
Iron (Fe)	.22	parts per million
Calcium (Ca)	31	parts per million
Magnesium (Mg)	12	parts per million
Sodium and Potassium (Na+K)	69	parts per million
Carbonate (CO_3)	0	parts per million
Bicarbonate (HCO_3)	211	parts per million
Soda (SO_4)	54	parts per million
Nitrate (NO_3)	1.7	parts per million
Chlorine (Cl)	33	parts per million
Total Solids	355	parts per million

In U. S. G. S. Water Supply Paper No. 237, the chemists said:

"The water is well adapted for irrigation and is suitable for a municipal supply, the chief hardness being of a temporary type. Small amounts of soda ash should be added before using this water in steam boilers."

The main river at Charlie's Butte is occasionally somewhat turbid because of the slight cutting of the soil in the banks of the stream. This turbidity is eliminated by sedimentation in the reservoirs through which the water passes. The water accumulated in the Haiwee reservoir is as clear in its appearance as that of the lakes of the high Sierras. The total solids, as determined by a year's average of Owens River water, are 328 parts per million, and in the Los Angeles River water they vary, according to the analyses of different chemists, from 467 to 573 parts per million. In other words, the mineral contents in the waters of the Los Angeles River are nearly double those of the Owens River at Charlie's Butte.

Tributary Creeks

The analyses made by the Government and by the Board of Consulting Engineers were of water taken from the river. There are, however, a number of side streams intercepted by the Aqueduct on its journey to the Haiwee reservoir, including Cottonwood Creek and Black Rock Springs. These waters that come directly off the granitic mountains are of a purer quality than the water in the river itself and the resulting water in the Haiwee reservoir, is a blended product, which will average better than the river. The amount of mineral content in the river waters varies with the different months of the year, being greater in May and June. Taking into consideration the mineral content observed by the Government during various months, and also the total vol-

COTTONWOOD LAKE REGION, JUNE 7, 1915
(Tributary to the Los Angeles Aqueduct)

NORTH TWIN LAKE, LOOKING SOUTH, JUNE 7, 1915
(Tributary to the Owens River)

umes of water discharged by the river, we get an average mineral content in the water for the year of observation of 328.45 parts per million, or 19.14 grains per gallon. The Black Rock Springs, which were publicly condemned by pernicious opponents of the project, contain but 8.98 grains of mineral matter per gallon. In all, about 25% of the water which reaches the Haiwee reservoir is taken from springs and side streams of this latter character. Considering that 25% of the water reaching the Haiwee reservoir is taken from the side streams and springs, the amount of dissolved salts in the resulting mixture with the river water is at least 20% less than indicated by the river samples, or 262 parts per million. Therefore, this blended water contains less than half the mineral content of the waters of the Los Angeles River.

The water that is obtained from artesian wells and from springs in Owens Valley closely resembles in purity the water of Black Rock Springs, and if these ground supplies are extensively developed, it will improve the quality of the water.

Comparative Analyses

The following table shows a comparison between the waters of Owens Valley and other waters in Southern California:

COMPARISON OF CHEMICAL CONTENTS BETWEEN OWENS VALLEY WATERS AND THOSE OF OTHER CALIFORNIA STREAMS.

	Lime	Bicarbonate	Total Solids (Parts per million)
Owens River at Charlie's Butte	31	211	328
Black Rock Springs			154
San Gabriel River at Azusa	45	176	208
San Gabriel at Rivera	55	211	245
Cottonwood Creek	51	246	413
Santa Ana at Corona	61	233	347
Santa Ana at Mentone	26	102	158
Santa Ynez River at Santa Barbara	101	265	714
Ventura River at Ventura	106	226	605
Kern River at Bakersfield	18	71	127
Los Angeles River at Los Angeles by E. H. Miller, City Chemist			480.7
Los Angeles River at Intake by Laird J. Stabler			532
Los Angeles River at City Pipes, Third and Hill, by Mark Walker			573

Surface Alkali

The waters of Owens River come from a range of mountains almost wholly granitic. There is some filtration through volcanic rocks in the northern part of the valley, but these igneous rocks are all low in salt contents and resistant to solubility. They are in distinct contrast to the sedimentary rocks, which are usually high in salt contents and from which the streams can readily absorb mineral matter. From the very nature of the geology of Owens Valley, the waters must be relatively pure. Frequently casual observers in Owens Valley note the alkali conditions on the surface of the moist lands, and infer that this indicates an alkaline water. This is not the case. Whenever ground water rises to within eight feet or less of the surface, evaporation immediately is established and all the salt contents of the water are left on the surface of the ground. Even if the water is of a very pure nature, if this evaporation is continued for a long period of years in a region such as Owens Valley, where the rainfall is very slight (5 inches per annum) and the surface is never flushed off by rain water, there will be an accumulation of these mineral salts on the surface of the ground. The cause of this is that the rate of evaporation is high and has been going on for a long period of time. It is a concentration of salt on the surface of the ground, just as there is a concentration of salt in Owens Lake, due to the fact that this lake has no outlet and that pure distilled water is continually being lost by evaporation and the mineral matter is left behind.

It was proved conclusively before the Aqueduct was begun that the Owens River water is of good quality, either for irrigation or for domestic uses.

Further data on the quality of water delivered through the Aqueduct, including reports of sanitary engineers and bacteriologists, are given in Appendix "B."

FEDERAL AID TO THE CITY

The Reclamation Act was passed on June 17th, 1902, and there immediately began a series of preliminary irrigation investigations throughout the arid regions by the Interior Department. Preliminary to the investigations, the water was filed upon by the agents of the Government under state law, and withdrawals of the public lands were made by the Secretary of the Interior under the federal provisions of the Reclamation Act. The Yuma project was adopted for construction by the Secretary of the Interior in May, 1904, and the Klamath project in May, 1905. These two projects exhausted all the money that was available for construction in California at that time.

No promises or agreements were ever made upon the part of the Reclamation Service, or any of its authorized agents to build any irrigation works in Owens Valley. This could only be done by the Secretary of the Interior. The Reclamation Service began work in Owens Valley in June, 1903, and stopped all work on the project in January, 1906, and has not prosecuted any field work in that region since that time. Surveys were made in the Owens Valley in the summer and fall of 1903 and in 1904, and stream measurements were continued subsequent to that date.

Conference in Washington

The intention of the City of Los Angeles to utilize the waters of Owens River became known to the California officials of the Reclamation Service for the first time in the latter part of October, 1904, and the Washington office was promptly notified. When the necessity of the City and the importance of the enterprise to that rapidly growing locality became known to the federal officials, they recognized that the greatest good to the greatest number required the use of the water by the City. A delegation, accompanied by W. B. Mathews, attorney for the Board, and Wm. Mulholland, its engineer, was sent by the Chamber of Commerce of the City of Los Angeles to Washington in June, 1906, and conferences were held with the Diretcor of the Geological Survey, Mr. Charles D. Walcott, Mr. F. H. Newell, Chief Engineer of the Reclamation Service; Gifford Pinchot, Chief Forester; the Secretary of the Interior, and the President of the United States. As a conclusion of these conferences at the White House, President Roosevelt dictated a memorandum covering the outline of the conferences, which reviewed the situation as it existed at that time.

Opposition of Private Interests

The President's letter is as follows:

"THE WHITE HOUSE,
"WASHINGTON, June 25, 1906.

"Messrs. Walcott and Pinchot state that there is no objection to permitting Los Angeles to use the water for irrigating purposes so far as there is a surplusage after the City's drinking, washing, fire and other needs have been met. They feel that no monopoly in an offensive sense is created by municipal ownership of the water as obtained under this bill, and that as a matter of fact, to attempt to deprive the City of Los Angeles of the right to use the water for irrigation would mean that for many years no use whatever could be made by it of the surplus water beyond that required for drinking and similar purposes.

"I am impressed by the fact that the chief opposition to this bill, aside from the opposition of the few settlers in Owens Valley (whose interest is genuine, but whose interest must unfortunately be disregarded in view of the infinitely greater interest to be served by putting the water in Los Angeles), comes from certain private power companies whose object evidently is for their own pecuniary interest to prevent the municipality from furnishing its

TWIN LAKES; HEADWATERS OF OWENS RIVER

own water. The people at the head of these power companies are doubtless respectable citizens, and if there is no law they have the right to seek their own pecuniary advantage in securing the control of this necessary of life for the City. Nevertheless, their opposition seems to me to afford one of the strongest arguments for passing the law, inasmuch as it ought not to be within the power of private individuals to control such a necessary of life as against the municipality itself.

"Under the circumstances, I decide, in accordance with the recommendations of the Director of the Geological Survey and the Chief of the Forestry Service, that the bill be approved, with the prohibition against the use of the water by municipality for irrigation struck out. I request, however, that there be put in the bill a prohibition against the City of Los Angeles ever selling or letting to any corporation or individual except a municipality, the right for that corporation or the individual itself to sell or sublet the water given to it or him by the City for irrigation purposes.

"Sincerely yours,

"THEODORE ROOSEVELT.

"P. S.—Having read the above aloud, I now find that everybody agrees to it,—you, Mr. Secretary, as well as Senator Flint, Director Walcott and Mr. Pinchot, and therefore I submit it with a far more satisfied heart than when I started to dictate this letter."

Rights of Way Granted

The subject of the withdrawal of the Reclamation Service from Owens Valley was referred to Congress by the President and an act known as "Public Number 395" was passed, granting to Los Angeles all necessary rights of way for canals and reservoirs for the carrying of water, and the necessary rights of way for electric plants and transmission lines, upon the presentation to the Interior Department of suitable maps of such proposed locations. The act provided for the sale of public lands and reservoir sites to the City of Los Angeles at the rate of $1.25 per acre. It was stipulated that the City of Los Angeles should return to the Reclamation Service the amount expended by the Federal Government for all its preliminary surveys, examinations and river measurements, not exceeding $14,000.00, which moneys had been spent on its investigations in Owens Valley. The act concludes that the City of Los Angeles is prohibited from ever selling or letting to any corporation or individual, except a municipality, the right for such corporation or individual to sell or sublet the water sold or given to it or him by the City. These latter provisions of the act of Congress have been incorporated in the City Charter, both with reference to water and power. This act provided for the withdrawal of the Reclamation Service from Owens Valley and the turning over of the data which the Government had collected to the City of Los Angeles. The details of the official correspondence, together with the minutes of the meetings of the Water Commissioners, and the act of Congress in full, are given in the First Annual Report of the Aqueduct.

Public Lands Withdrawn

In order to further aid the City, President Roosevelt, by an executive order, withdrew a broad belt of public land along the Owens River and adjacent to the contemplated location of the Aqueduct, pending the time when the City could file definite right-of-way maps as required by law. The total area so withdrawn amounted to 298,880 acres. As the definite locations progressed, the excess lands were restored to entry, on recommendation of the City. Artesian public lands also were bought in Owens Valley on the theory that they were in fact reservoir lands, in which the storage was underground, and after careful consideration and geological investigations in the field, this contention of the City was acceded to by the Interior Department.

Railroad Lands

The Southern Pacific Railroad Company, through its land grants, owns alternate sections, extending from a point near Freeman practically through to the San Fernando Valley; or for 100 miles along the route of the

Aqueduct. The railroad company sold to the city about 1000 acres of these lands for right of way for $5.00 per acre.

No Rights Invaded

The people of Owens Valley never were requested to transfer or surrender to the Reclamation Service any water rights or lands, and no promise or agreement was ever made by the Reclamation Service to build this project. Notwithstanding these facts they naturally were greatly disappointed and irritated over the action of the City of Los Angeles and the federal authorities. They were apprehensive of substantial injury to their valley from the taking of such large quantities of water from it. The mere fact that officers of the Federal Government had appeared in this remote region, and were considering the construction of large irrigation works, had led them to anticipate a great development. Their fears of prospective injury, due to the action of the City of Los Angeles in their valley, however, were groundless. The City caused to be built a standard gauge railroad to the south, connecting with the Southern Pacific main line, thus giving them the first-class transportation facilities which they so urgently needed. The valley has developed at an accelerated rate, both in population and wealth from the time of the advent of the City.

RED ROCK CANYON

GENERAL DESCRIPTION OF THE AQUEDUCT

Storage Capacity of Reservoirs, Type of Canals, Conduits and Tunnels

The Aqueduct proper consists of a series of six storage reservoirs and 215 miles of conduit.* The largest reservoir site is on the main stream at Long Valley,* with an elevation of 6,650 feet at the dam site, about fifty miles above the point where the Aqueduct diverts the river. Here, with a dam of 160 feet in height, 340,000 acre feet of water may be impounded, or enough water to cover 340,000 acres one foot deep, which is 28,000 acre feet less than the capacity of the Ashokan reservoir, constructed by the City of New York. Its province will be to hold over waters from years of plenty to groups of years of extreme drouth, such as occur only three or four times in a century.

The construction of this reservoir has not yet been undertaken and the continuous measurements of the available stream flow have not, as yet, revealed an occasion for its use, except by ignoring the very large available supply that may be recovered, at much less cost, in the artesian portion of the valley below. An artesian well district, approaching 50 miles in length, has been outlined by well borings in the floor of Owens Valley.

Diversion Canal

Fifty miles below this Long Valley reservoir site, the main canal, with a capacity of over 800 cubic feet per second, and a width of 65 feet on the bottom, diverts the river and various tributaries as they are passed, discharging into the Haiwee reservoir 60 miles below the intake. This 900 second-foot canal will carry all ordinary summer flood waters caused by the melting of snow. The Haiwee reservoir, with a capacity of 63,800 acre feet, will regulate these flood waters into a uniform flow of 422 cubic feet per second. The elevation of the high water in this reservoir will be 3,760 feet, and the area of the water surface 2,100 acres. The capacity is sufficient to run the full supply of the Aqueduct for 75 days without any replenishment.

The first 20 miles of the canal, situated in the moist artesian lands of Owens Valley, was excavated by hydraulic dredges, and forms practically a modified river course, which is not lined. A large number of springs occur in the floor of the valley, which will augment the flow in this section.

For the next 40 miles to the Haiwee reservoir, the canal is concrete-lined but not covered. Below the Haiwee reservoir to the suburbs of Los Angeles, the Aqueduct will be completely lined and covered with concrete. This portion skirts the eastern base of the Sierra Nevadas, crossing the western arm of the Mojave Desert about 35 miles southwest of the town of Mojave, and then passes under the Coast Range with the Elizabeth Tunnel, 5.1 miles in length and sixty miles north of the City.

Tunneling the Sierra

For 50 miles, the line is forced into regions of great topographic severity along the eastern face of the Sierra. Tunnel follows tunnel for mile after mile. Frequently, on the steeper and more threatening slopes, as in the Little Lake and Grapevine divisions, the tunnel line does not come to the surface at all, but was reached for construction purposes by side drifts or adits through which the excavated material and the concrete for lining were conveyed. Canyons are crossed with steel pipes under pressure heads varying from 60 to 850 feet. The materials for construction were conveyed up the mountain sides in many instances by aerial trams. Through the Mojave desert there is 70 miles of "cut-and-cover" construc-

*See Plate No. 4. Profile Los Angeles Aqueduct—in map pocket.
See Plate No. 5. Map of Los Angeles Aqueduct—in map pocket.
See Plate No. 7. Map of Long Valley Reservoir—in map pocket.

tion in the desert plain. Here steam shovels excavated the necessary trench about 12 feet wide and 10 feet deep, in which the Aqueduct was built, the cover being kept below the surface of the ground so as to offer no obstruction to the occasional "cloudbursts" which at rare intervals run down the desert slopes.

Fairmont Reservoir

The Fairmont reservoir is located at the south end of this line, where the Elizabeth Tunnel pierces the Coast range. This reservoir has a capacity of 7,620 acre feet, with a dam 115 feet high. The elevation of the high water is 3,036 feet and the area of the water surface is 165 acres. This reservoir regulates the flow through the power conduits below to meet the hourly fluctuations for power. The inflow into the reservoir will be that carried by the Aqueduct from Haiwee, namely 430 second feet. The outflow from the reservoir, however, will vary with the power demand, which in turn depends upon the consumption for lighting and industrial purposes.

The Aqueduct has been designed to deliver 400 cubic feet per second of water in the San Fernando reservoir. The conduit between Haiwee and Fairmont, however, is designed to carry 430 cubic feet per second. The 30 second feet additional is to provide for assumed seepage losses in the canal and evaporation losses from the reservoirs south of Haiwee. These losses will probably not be greater than 10 second feet. If at any time it is necessary to empty the Fairmont reservoir, the 20 second feet remaining will go toward filling the reservoir again without interrupting the flow of 400 second feet to the City.

Power Development

There is available in the San Francisquito Canyon a fall of 1,470 feet for the generation of power. In addition to the drop in the San Francisquito canyon, there is available for power development a fall of 190 feet at the Haiwee reservoir and 190 feet at the point where the Aqueduct discharges into the upper San Fernando reservoir. This subject is treated in detail in the chapter on "Permanent Hydraulic Power Development."

Dry Canyon Reservoir

The Dry Canyon reservoir is located at the south end of the 1,000 second-foot tunnels in the Saugus Division. This reservoir has a capacity of 1325 acre feet, with a dam 61 feet in height. The elevation of the high water will be 1,505 feet and the area of the water surface 61 acres.

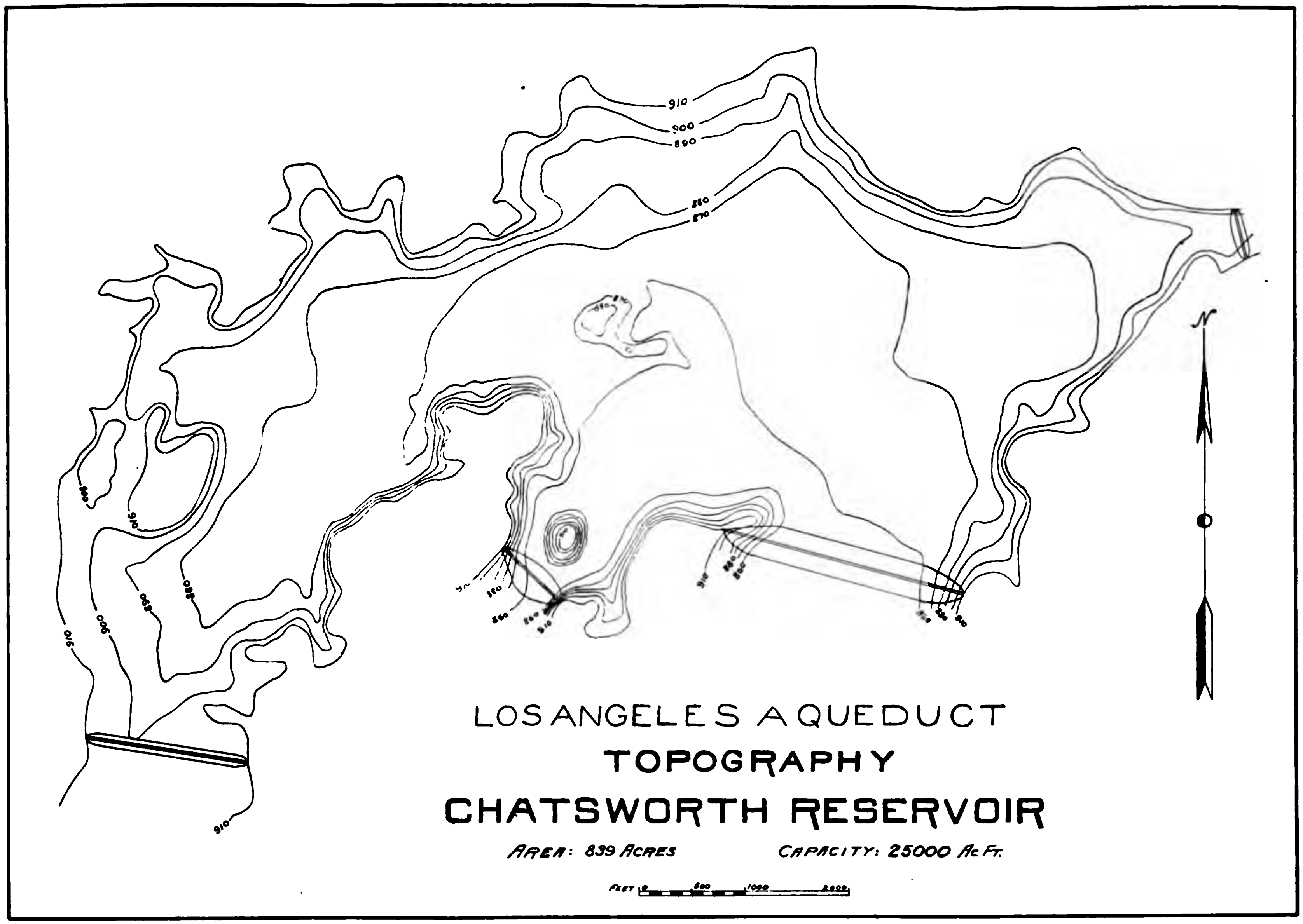
San Fernando Reservoir*

The Los Angeles Aqueduct terminates at the San Fernando reservoirs. These reservoirs and any auxiliary construction from San Fernando to Los Angeles will be part of the distributing system, and as such are to be built by the City Water Department. The function of these reservoirs is to regulate for the seasonal demand and permit of a more efficient use of the Aqueduct. While 400 second feet will be continuously discharged into them, the water may be drawn from them in a variable amount to meet the fluctuating requirements of the consumers. They will also insure an adequate emergency domestic supply for the City of Los Angeles if the flow through the Aqueduct should be interrupted for a considerable period. If the surplus waters of the Aqueduct above the requirements of the City be spread upon the San Fernando Valley, it will result in the replenishment of the underground waters and the increased flow of the Los Angeles River. If, for any unforeseen reason, the flow of the Aqueduct is stopped for a long time, these underground waters would also be available to the City. There are two reservoirs at the end of the Aqueduct at San Fernando, the lower one of which is under construction. The upper one, known as "San Fernando Reservoir No. 1," will have an ultimate high water elevation of 1,275 feet. The area of the water surface will be 460 acres and the capacity of the reservoir will be 15,940 acre feet. It is proposed to construct this reservoir when the surplus waters of the Aqueduct are in beneficial use to such an extent as to make it necessary. The

*See Plate No. 6. Map of San Fernando Reservoir —in map pocket.

Construction of Lower San Fernando Dam, July, 1913

Lower San Fernando Reservoir Partially Filled for Irrigation, Season of 1915



CONSTRUCTION OF THIS RESERVOIR IS YET TO BE UNDERTAKEN

lower one, "San Fernando Reservoir No. 2," will have an ultimate high water elevation of 1,135 feet. The area of the water surface will be 410 acres and its capacity 23,000 acre feet.

Chatsworth Reservoir

In the western end of the San Fernando Valley there is a reservoir site known as Chatsworth, which, with a water elevation of 910 feet and a dam 60 feet high, would have a storage capacity of 25,689 acre feet. The size and location of this reservoir is such that it can be utilized very effectually for the impounding of the winter water of the Aqueduct, and its distribution during the summer months in the western end of the San Fernando Valley. It is very important for these reasons, and undoubtedly will be used at some time for the full development of the Aqueduct and irrigation interests in the vicinity of Los Angeles.*

The storage of waters in uncovered reservoirs at low elevations for a long time, under the bright sunshine of Southern California, is apt to promote the growth of aqueous plants known as "Algæ." Although this plant life does not impair the quality of the water, it imparts a peculiar taste to it. For this reason and for conditions of safety, the domestic supply for the City is conducted around these reservoirs, but suitable connections also will be provided to supply the City directly from them.

Terminus of the Aqueduct

Aqueduct construction ended at the point where it enters the San Fernando Valley, instead of being continued on to the City of Los Angeles, because that point, due to its topographic position and elevation of 1,465 feet, was the logical one from which to begin a general distribution system for the entire region extending from the Sierra Madre mountains to the sea, and because the bonding power of the City could at that time bring the work no farther, according to the estimates prepared by the Board of Consulting Engineers.

COEFFICIENTS OF FLOW

The available engineering data bearing on the coefficients of friction governing the flow of water in lined channels was supplemented by field examinations of local conditions in Southern California, where many lined conduits have been constructed. While in new work of different classes, these coefficients are the same for all localities, the real question of interest is how they may change in localities of different latitudes and with waters of different character.

In some of the conduits of the Metropolitan Water District of Massachusetts and also in the Northwestern portion of this country, there is a growth of fungus or moss, which materially reduces their carrying capacity with their increased age. In all the covered concrete conduits in Southern California that were examined, no indication of this growth could be found, but the striking feature that was developed is that in the uncovered conduits, where the sunlight has the opportunity of developing vegetable growth, a lichen-like moss rapidly forms on the sides of the ditch, and this is supplemented by a long fibrous grass, and the two together very materially reduce the capacity. In most of the covered and plastered conduits, the value of "n," in the Kutter formula, will vary from .011 to .013, but in the open conduit this coefficient will be increased to as much as .020. This coefficient, therefore, would vary with concrete conduits in Southern California, depending upon whether or not they were covered.

Deterioration of Steel Pipe

Extensive observations have been made by Mr. Waldo Smith, Chief Engineer of the New York Aqueduct, to determine the value of "C" in the Chezy formula, in riveted steel pipe. He found in a 42-inch pipe, built by the City of Newark in 1892, that for velocities of 4 feet per second, in 1896 the value of "C" was 107.5, and in 1907, 11 years later, this value had dropped to 88. In the case of a 72-inch riveted steel pipe, built for the Jersey City Water Supply Company in June, 1903, with velocities of 3 feet per second, the coefficient "C" when new was 109; in 1904 it was 100; in 1905 it was 97; in 1908 it was 85; in 1909 it was 91; and in

*See Plate No. 8. Reservoir Capacities—in map pocket.

1911 it was 89. About September, 1908, a plant for treating this water was installed at Boonton, New Jersey, and since that date the water has been continuously so treated. Immediately following the introduction of this treatment, large masses of vegetable and other algal matter were discharged from the pipe, and the improvement in its carrying capacity, as indicated by the experiments of 1908 and 1909, was undoubtedly due to this cause. The Newark pipe was covered with California asphalt when laid. Tubercles formed in this pipe, some of them projecting as much as ¾ of an inch, although no single one covered an area greater than 2 inches in diameter.

There is no such rate of deterioration with age to be expected in the pipe through which the waters of the Los Angeles Aqueduct run. Two tests were made of riveted pipe in the Los Angeles City Water Works, that of the 5-year-old, 52-inch riveted steel pipe, showing a value for "C" of 121.2; while in the 8-year-old 18-inch riveted steel pipe, the coefficients ranged, with different velocities, from 100 to 103. It is worthy of note that the older pipe shows the lower coefficient. The difference is largely accounted for in the greater relative roughness of the smaller pipe, as both had the same size rivets and thickness of metal. The water that is run through these pipes is of a neutral character and does not seem to be so active in its attack on the metal as some eastern waters that are of a softer and more acid nature.

Results of observations of conduits in Southern California indicated that a coefficient of .012 for "n" in the Kutter formula would be safe in tunnels or covered conduits, lined with concrete and plastered, but for open canal work, where sand is apt to get into the channel, and where vegetation occurs, notwithstanding the fact that the sides may be smoothly plastered, the value of "n" should be increased to .018 or .020.

The Board of Consulting Engineers who reviewed the plans of the Los Angeles Aqueduct in December, 1906, suggested the following coefficients: For cement or smoothly plastered masonry N = .018; for concrete-lined tunnels or common masonry conduits N = .014; for steel pipe with rivet heads and seams projecting on the interior N = .016; for earth canals with bottom as left by dredging N = .0275. The value of "C" corresponding to the value of "n" = .016 in the Kutter formula, with a 10-foot pipe, with a slope of 1 foot in 1,000, is 107.

Coefficients Determined

After obtaining the results of the determination of decreased carrying capacity with age, as found in the New York and Jersey City pipes, the coefficient "C" was taken as 90, in the design of steel pipe for the Aqueduct, which would be equivalent to the value of "n" = .019. The coefficient of the lined tunnels and covered conduits was taken as .014, as recommended by the Board. This covers 75 per cent. of the line. For the open and lined conduit from the north end of the Alabama hills to the Haiwee Reservoir, the capacity of which is 900 second feet, and the purpose of which is to collect the flood waters in the Haiwee Reservoir, the value of "N" was taken as .014 instead of .018, as recommended. This is a plastered conduit which will be running full only for perhaps 60 or 90 days out of the year. The rest of the time it will be discharging less than half capacity. This condition is unfavorable to vegetable growth on the sides of the ditch, and there is an abundance of opportunity to clean this portion of the canal without interfering with the continuous discharge of the Aqueduct to the City. The Aqueduct for 60 miles, from Owens River to the Haiwee storage reservoir, has a capacity of 900 second feet, and below the Haiwee Reservoir the standard section has a designed capacity of 430 second feet, so that a slight reduction in the capacity of the larger canal used for the delivery of flood water does not affect materially the delivery of water in other sections of the conduit. With the coefficients used for the pipes and covered lined conduits from the Haiwee Reservoir south, it is certain that the Aqueduct has an actual capacity in excess of the theoretical capacity for which it was designed.

PRELIMINARY WORK

Building of Roads and Development of Water Supply and Power for Construction Purposes

Exact levels being of prime importance in the construction of an aqueduct that has a fall in some instances as low as one foot per mile, a line of precise levels was run from San Fernando up the San Francisquito Canyon around the west end of the Antelope Valley, and thence north of Mojave along the main wagon road on the eastern base of the Sierra Nevadas to the intake of the canal. The work was done with instruments and methods such as are used by the U. S. Geological Survey.

About 1,500 miles of lines were surveyed. The country, as finally developed by all the surveys, embraces an average vertical distance of 200 feet for the entire length of the Aqueduct, the horizontal distance varying with the slope of the ground. Several trial routes were surveyed and estimates made, and modifications of the preliminary location were made in the route from the Haiwee reservoir south, the most important being substitution of a line via San Francisquito Canyon for the route via Palmdale and Acton to Big Tejunga, saving 20 miles in distance over a very rough country and shortening the longest tunnel by 1¼ miles. The general map of the Aqueduct shows the route followed.

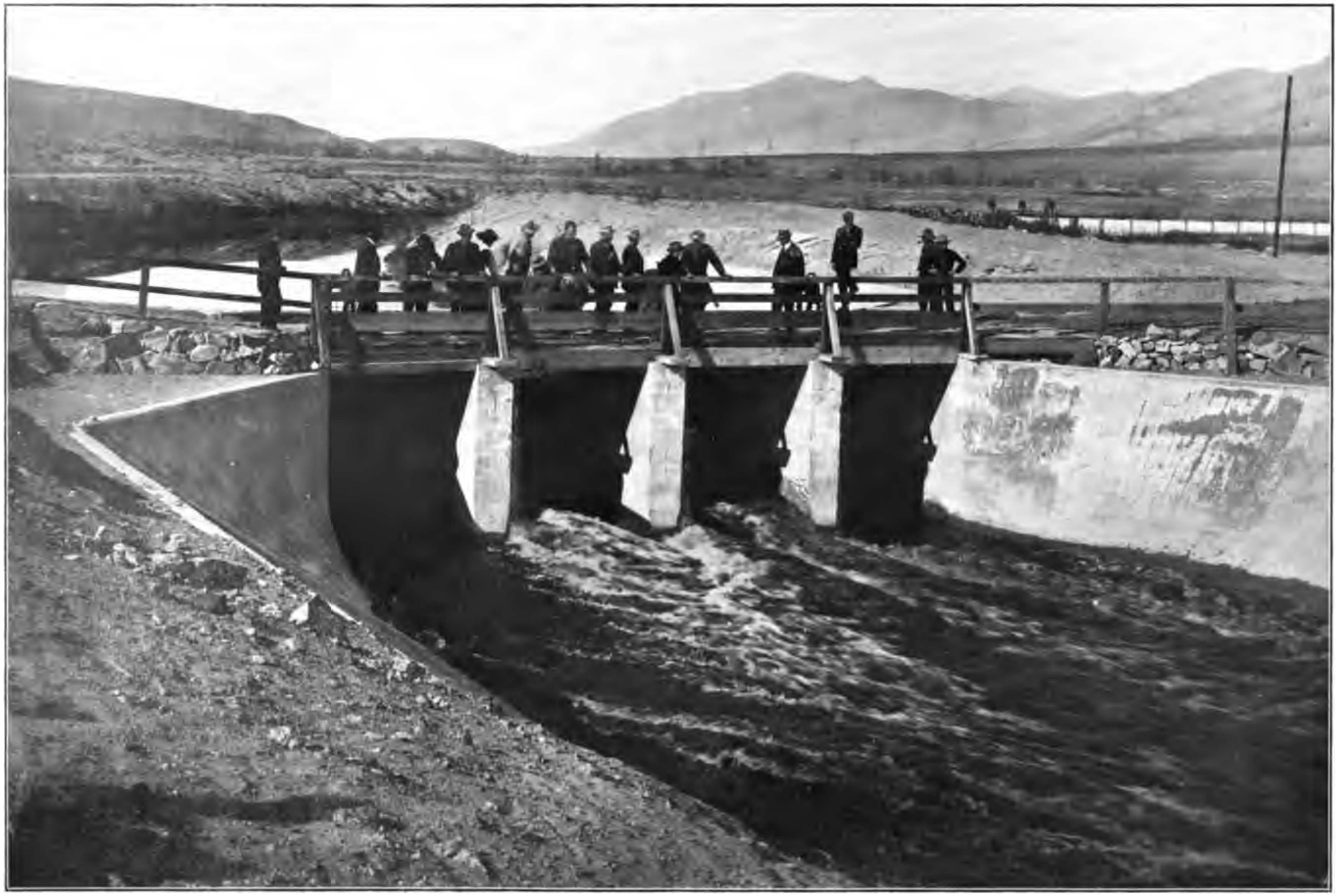
The controlling elevations of the Aqueduct are: 1. Black Rock Springs, fixing the intake in the Owens River at an elevation of 3,814.8 in order that the waters of the spring may be diverted into the conduit. 2. Haiwee reservoir at an elevation of 3,760 to insure sufficient capacity for seasonal flood regulation. 3. Fairmont reservoir at an elevation of 3,035. 4. San Fernando reservoir at the southerly extremity of the Aqueduct. A grade elevation of 3,545 at the gateway below Haiwee Reservoir may also be said to be fixed. There is thus an available fall of 54.8 feet for the 60 miles of diversion conduit, or an average gradient of .91 feet per mile and 0.173 feet per thousand.

From the gateway below Haiwee to the water surface of Fairmont Reservoir, the total available drop is 510 feet. As the Aqueduct passes through all kinds of country and includes various types of conduits, uniform gradient could not be used. Distribution of gradients was required for the different types of conduits and the various kinds of material encountered. Grade study was made to determine the most economical possible distribution of this fall.

The Aqueduct between Haiwee and Fairmont consists of lined canal in earth in Rose Valley Division; hard rock tunnels, covered and lined canal in rock bench, and steel siphons in the Little Lake and Grapevine Divisions; lined canal in Freeman Division; earth, soft rock and hard rock tunnels, siphon and canals in Jawbone division, and covered conduit through the Mojave Desert. For each of these types in each division of country, unit construction costs were estimated for various grades. The net and gross cost curves coincide at a point corresponding to the gradient recommended for the section in question by the Board of Consulting Engineers.

Tunnel Cross-Sections

A study was also made to determine the economic cross sectional area of the Elizabeth Tunnel. This tunnel forms a part of the power pressure conduit directly connecting Fairmont reservoir with the first San Francisquito power plant. If the cross sectional area of the conduit is increased, the slope required to maintain any given velocity is decreased, and a greater net drop is available for the development of electrical energy. In the Chief En-



OPENING THE AQUEDUCT HEADGATES, FEBRUARY 13, 1913

gineer's First Annual Report, (March, 1907) Appendix "J,." Mr. E. F. Scattergood, Consulting Electrical Engineer, estimates the net annual income for each horse power developed at $38.00. The assumed efficiency of the combined system, allowing for losses in pipe lines, water wheels, generators and transmission lines, was 55.2 per cent. Hence each theoretical horse power developed will deliver actually only 0.552 horse power, or the value of each theoretical horse power is $20.96. Capitalizing $20.96 at 5 per cent. gives $419.20 as the asset of the City for each theoretical horse power. Every foot of the head required in the tunnel reduces correspondingly the available power drop in San Francisquito Canyon, and represents a direct loss in power output, which can be determined for any assumed rate of flow. Every horse power so lost represents a lost asset to the City of $419.20. In estimating the cost of the tunnel, the loss in capital to the City which is represented by actual construction cost plus the value of "lost power," was considered. As the power drop would not be revenue producing until several years after completion of the tunnel, interest on the estimated construction cost was added at the rate of 5 per cent. for 5 years. The sum of construction cost, plus interest for 5 years, and the value of "lost power" were added and tabulated as "Gross Cost." The economic area of cross section was found to be 90 square feet.

Studies similar to that of the Elizabeth Tunnel were made for the various tunnels, siphons, and canals in the Saugus Division. The power value here was considerably reduced on account of its necessarily being a uniform output and not subject to regulation for peak loads. The unit power value was assumed equal to 69 per cent. of the unit power developed in the San Francisquito Canyon. The possibilities of future power development, therefore, were carefully conserved in designing the Aqueduct.

Water Supply for Construction Purposes

The water supply for camp and construction purposes was one of the most difficult problems encountered in the construction of the Aqueduct. The extremely arid nature of the country through which the greater portion of the Aqueduct is built greatly increased the difficulties to be overcome in obtaining a water supply. Water is very scarce and in many instances had to be carried for miles to the line of the Aqueduct. A line of pipe was laid virtually paralleling the Aqueduct from San Fernando to the intake. Branch lines were laid up side canyons, and almost every spring or stream along the Aqueduct was led into the main line. Large storage tanks were installed at the camps as a part of the movable equipment, and the flow of these springs and creeks accumulated during the night, that it might be available during the day. In all, 269 miles of pipe was laid for construction purposes at a cost of $299,000.00.

The Freeman and Jawbone divisions received their water supply from three springs and two open streams located about 5 miles from the mouth of Sage Canyon. The water was collected through infiltration pipes, carried through a 2-inch pipe line under high pressure a distance of two miles into a sand box. From here it was taken through five miles of 3½-inch O. D. casing to the line of the Aqueduct, which it paralleled for 4 miles, to Red Rock Summit and was there discharged into a storage reservoir of 300,000 gallons capacity. From this reservoir a pipe line 14 miles long, with branch lines wherever necessary, conveyed an ample supply of excellent water for camp and construction use along the Aqueduct to Water Canyon.

The Tehachapi-Jawbone line was supplied from a well 225 feet deep at Proctor, near Tehachapi. The water was raised by a centrifugal pump, driven by a gasoline engine, and was discharged into a 200,000-gallon reservoir. A 4-inch line from the reservoir followed the Southern Pacific Railroad for about 10 miles to a point a short distance south of the railroad station at Warren, where it joined the line of the Aqueduct, at its intersection with the railroad, four miles north of Mojave. From here the pipe followed the Aqueduct north 14 miles to Sun Canyon. Near the crossing of the Aqueduct and the railroad, a 60,000-gallon reservoir was built. It was supplied from the

Jawbone-Tehachapi pipe line, and from it water was delivered through 2 miles of 4-inch pipe to the warehouse, machine shop, etc., at Mojave. A second branch of 2-inch pipe paralleled the Aqueduct for 8 miles south.

The source of the Kings Canyon line was a mountain stream near Neenach, California. A line of 4-inch pipe carried the water 4 miles to the Aqueduct, and thence paralleled it for 12 miles to the North Portal of the Elizabeth Tunnel, and to the south end of the Antelope siphon. Water was available at any point along its route.

The water for hydraulic operations at the Haiwee Dam was obtained from Haiwee and Hogback creeks. More than 8 miles of main pipe lines were laid, varying in diameter from 6 to 12 inches. In the Saugus Division wells had to be driven in the bed of near-by canyons, pumps installed and the water pumped up to the grade of the Aqueduct.

Electric Power

The power required between the San Fernando reservoirs and the Fairmont Tufa Mill was provided by the construction of a 30,000-volt transmission line, approximately 40 miles in length and supplied from the Castaic sub-station of the Southern California Edison Company. The total cost delivered averaged approximately 1.75 cents per kilowatt hour, which represents the cost of the power, the cost of operating and maintaining the lines and transformer stations, and the difference between the original cost and the salvage value of the system.

The Cottonwood power plant, of 2,100 horse power capacity, and the Division Creek power plant No. 2, of 800 horse power capacity, in conjunction with a 169-mile, 30,000-volt transmission line, extending along the Aqueduct from the intake in Owens Valley to the Pinto Hills near Mojave and thence to the cement plant, supplied the power for construction for the Aqueduct from the Pinto Hills north, and a portion of the power necessary for operating the cement plant.

The two power plants and the 45 miles of transmission line in Owens Valley are of a permanent character.

This system supplied approximately 28,900,000 kilowatt hours at step-down voltages along the Aqueduct, at an average cost of 1.25 cents per kilowatt hour, including the total cost of constructing, operating and maintaining the system, less the salvage value, charging against the system a percentage for general administration, but no percentage for interest on the investment during the period of its use.

The cost of supplying electric power proved to be within 2½ per cent. of the original estimates. The original estimate of the cost of supplying power by other means was much higher, and the experience of the Division Engineers proved the electric power to be much more desirable, even at the same cost, because of its greater convenience and reliability.

Transformer Banks

This resulted in the use of portable out-door type transformer banks, even for the supplying of units as low as from 5 to 10 horse power, in preference to the use of gas engines.

An accompanying cut shows one of the small banks of out-door type transformers, connected in portable form, and another cut shows the manner of connecting to the 30,000-volt line by means of clips and spiral springs, extending from the buckarm, as shown, to the transmission wire. This is done without shutting down, which would be impracticable with so many sub-stations.

The employment of experienced linemen for patrolling and maintaining the lines, and connecting and disconnecting transformer banks, resulted in economy and efficiency. In the operation of these two high-voltage power systems, during the whole 5 years of Aqueduct construction, no employee connected with the systems was hurt by electricity.

Telephone Lines

The main telephone line extends from the offices in the City to the intake in Owens Valley, a distance of approximately 240 miles, and consists of two No. 10 copper wires, on 4x6 redwood poles. The line was indispensable in carrying cut construction work effectively, and is manufactured for the operation of the Aqueduct.

Outdoor Type of Transformer Used in Construction Work

Manner of Making Connections to 30,000-volt Line During Construction Work

During construction, a local telephone system was provided for each division, making it possible to communicate with every camp along the Aqueduct from the central offices.

Roads and Trails

In the mountainous divisions, such as Grapevine, Little Lake and Jawbone, where the Aqueduct location lies from 900 to 1,200 feet above the desert level, an adequate system of roads and trails had to be provided. The most noteworthy of these systems was the "Gray Ridge Road," which formed a means of communication between the division headquarters at Cinco and the almost continuous chain of tunnels extending from the Jawbone Canyon south. It was built with a maximum grade of 6 per cent. This road cost a total of $44,000.00 or about $5,000.00 a mile. Auxiliary roads and a network of trails served for all necessary haulage in this division.

In the desert divisions roads were built from the nearest shipping point on the railroad to the Aqueduct and then paralleled it for practically its entire length through such divisions. The total construction expense of 505 miles of roads and trails was $274,300.00, and $33,140.00 was expended for their maintenance. The total cost for roads and trails per foot of Aqueduct waterway was 25.6 cents.

Housings

Housing of the forces engaged in the construction of the Aqueduct required lodgings, dwellings, offices, mess houses, hospitals, warehouses and miscellaneous structures, as blacksmith and machine shops, tunnel plants, hay barns and stables.

The climate along the Aqueduct varies from the intense summer heat of the desert, when the thermometer reaches 110 degrees, to a temperature approaching zero in winter. The effort was made to make the lodgings comfortable in both summer and winter. Bunk houses for laborers were made to accommodate from one to eight men to the room, and each room had an outside window. The cost of these buildings was about $25.00 for each man housed. Four-room dwellings were erected for the Division Engineers, who paid a monthly rent to the City sufficient to return the investment. These dwellings each cost from $600.00 to $900.00, depending upon the location and cost of hauling the material.

Many of the Aqueduct buildings, such as offices, dwellings and bunk houses, were designed so that they could be taken down in sections, loaded on wagons and expeditiously erected again at some other point. These portable houses were used on the Diversion Canal in the Owens Valley, and on the long stretch of light work in the Mojave Desert.

The total expenditure for buildings used in connection with the Aqueduct construction was $341,554.00. The losses due to fire amounted to $12,826.00. The salvage value of the buildings was $18,881.00, making the net cost of housing $322,672.00. The total revenue from rentals of these buildings was $27,776.00.

Following is a statement of the number of buildings erected:

Bunk houses, cottages and engineer's residences	248
Machine shops	10
Compressor plants	23
Barns and hay sheds	33
Warehouses	36
Office buildings	25
Hospitals	8
Sawmills	7
Powder magazines	50
Garages	1
Tents	1600
Miscellaneous small shops, sheds, corrals, etc.	250
Total	2291

These do not include the buildings at the Cement Mill.

TRANSPORTATION

Railroad Through Desert Built by Southern Pacific Under Traffic Contract With the City

The region through which the Aqueduct had to be built, from the Coast range north, was an unoccupied desert, in which very little forage or water could be obtained for teams. The amount of freight that had to be transported in this region was estimated to be about 20 million ton-miles. North of Mojave it was computed that 210,000 tons had to be moved an average distance of about 65 miles, or nearly 14 million ton-miles of freight. If this hauling were done by wagons, the forage for the animals engaged in the work would of itself be a very large item. A freight team will not make over 20 miles a day, or a round trip of 10 miles, and will consume at least 25 pounds of forage fo the animal per day. With an average haul of 65 miles, each animal would require 162 pounds of forage for the round trip, or nearly 10 per cent. of the total weight that it could haul.

Bids were called for in December, 1907, for the transportation of freight by teams, and the lowest bid offered was 28 cents per ton mile. This was for the portion of the line on which the roads were the best. Numerous bids were subsequently obtained for the hauling of freight over the level desert roads, particularly west of Mojave, and 25 cents per ton-mile was the lowest figure obtained except in one small and unusual contract.

Rail Transportation

It therefore became necessary to study the question of rail transportation, and a preliminary railway location was made from Mojave to Owens Lake. The amount of freight to be hauled, together with the estimated costs of constructing, operating and subsequently selling as salvaged material the track that was laid, resulted in the conclusion that the City could build such a railroad and operate it at a cost of 10 cents per ton mile for freight, or about one-third of the amount that was bid by contractors.

As the work on the Aqueduct progressed, the City purchased its own live stock and wagons and thoroughly organized the wagon transportation business from Mojave west, and it was found that by using 12-animal teams with one driver and two wagons, freight could be transported at a cost of from 12 to 15 cents per ton-mile, when it had to be moved in great bulk, and this was done over the good roads in the flat country west of Mojave and Lancaster, for which region no railroad was built.

For a long haul of 130 miles from Mojave north, it was decided that it was necessary to have a railroad. The Owens Valley region was served by a narrow gauge railroad, which comes south from the Central Pacific at Reno and Hazen and passes over two high summits, one of which is 7,000 feet in elevation, but this road did not come south of Owens Valley points. This road is a portion of the Harriman system. It was believed that the building of a broad gauge railroad from Mojave north to Owens Valley would make this agricultural and mining region tributary to Los Angeles, and would ultimately result in a standard railroad connection through to the Central Pacific, which would be decidedly to the advantage of Southern California. For this reason it was desirable to have this road built by a railroad corporation, rather than by the City, as the City would be forced to abandon the line after it was through with it for construction purposes.

A CONSTRUCTION ROAD IN SAN FRANCISQUITO CANYON

HAULING WITH TRACTORS ON THE MOJAVE DESERT

Southern Pacific Interested

Preliminary negotiations were entered into with the Santa Fe Railroad, Southern Pacific Company, and the Western Pacific Railroad, but the only organization that showed interest in the situation was the Southern Pacific Company. The general route of the road necessary for the construction of the Aqueduct was outlined, with a schedule of dates, showing when it would be necessary for the road to be built to certain points in order to facilitate the work, and figures on this basis were obtained from the Southern Pacific Company. The road was considered as extending from Mojave to Olancha, a distance of 100 miles, by the line of the City's survey, and 118 miles by the route proposed by the Southern Pacific Company. The Southern Pacific line made a detour to the east of the Freeman Division, which made it necessary for the City to build and operate six miles of branch line in the Red Rock Canyon of the Jawbone division. This extra cost of the Red Rock Spur was added, in the comparative estimate, to the figures of the Southern Pacific Company. While the Southern Pacific line, in this estimate, was considered as stopping at Olancha, where the City road would stop, as a matter of fact it continued 20 miles beyond Olancha through Lone Pine to Owenyo, and the estimate, therefore, should show a much more favorable figure for the Southern Pacific proposition.

Cost of Railroad Construction

The estimated cost of building the road by the City was $1,390,000.00 with a salvage value of $350,000.00. The rail figured upon for the City road was 50-pound, which would be too light for a commercial railroad. After figuring on interest, equipment, operating expenses and salvage, the cost of the transportation of freight over the City road was estimated at $1,634,237.00. Under the tariff schedule submitted by the Southern Pacific Company, the cost of transportation was $837,358.00, to which was added the cost of the Red Rock Road $88,000.00, operating the Red Rock Railroad $18,200.00, distribution of freight on the Freeman Division at an excess cost of $63,000.00, (due to the less favorable location of the Southern Pacific Road,) making a total of $1,006,558.00. This showed a net saving to the City of $627,679.00 from acceptance of the Southern Pacific bid.

In addition to the local freight to be moved north of Mojave, there was a large amount of material and supplies to be moved over the existing main line. Nearly one-half of this consisted of cement, which had a short haul from Tehachapi to Mojave of 17½ miles. Machinery and steel for the siphons would have to be shipped from the East, over transcontinental lines, amounting in all to possibly 20,000 tons. The suggestion was made by the railroad people that if they could obtain the routing of this eastern freight, a still lower bid could be made on the transportation of the local freight from Mojave north. The statement was made that this eastern freight would be handled at the minimum schedule rates and as low as any other transcontinental road would transport it. The reduction that was offered in the local freight rates, from Mojave north, in case this eastern freight could be controlled in this manner, amounted to fully $140,000.00.

At a conference on November 25th, 1907, between the Board of Public Works; a Committee of the Chamber of Commerce, the full Board of Water Commissioners, Engineers Mulholland and Lippincott and Attorney W. B. Mathews, it was decided that no arrangements for building the new road or transporting the Aqueduct freight over the same, or routing the outside freight, should be made with any company except after advertisement for bids, the contract to be awarded to the lowest regular responsible bidder.

Formal specifications were prepared and advertisement made, and on the 10th day of April, 1908, a contract was entered into with the Southern Pacific Company for construction of the railroad and the transportation of local freight, the routing of the transcontinental freight being given to the Southern Pacific Company.

Saving in Freight Rates

To summarize, the Board of Public Works received bids for the transporting of freight by wagon haul of 28 cents per ton-mile: the estimate of their engineers for the building and operation of a City railroad would result in a cost of 10 cents per ton mile; and a contract was entered into with the Southern Pacific Company for the building of this road and the handling of freight at an average cost of 4½ cents per ton-mile.

The Southern Pacific Company built this road nearly a year in advance of the contract time schedule, and the tariff sheets, that were embodied in the contract for the City, became the rates which were paid by all private parties for the transportation of freight over this line during the period in which the Aqueduct was built.

The federal laws, regulating railroad rates and prohibiting special rates, make specific exceptions in favor of federal, state or municipal institutions. The City of Los Angeles obtained from the Santa Fe Railroad and the Southern Pacific Company one-half class rates on local freights shipped for the construction of the Los Angeles Aqueduct, on lines other than the one which was constructed specifically for the City. In cases where the commodity rate was lower than the class rate, the City received the benefit of the commodity rate. All freight moving to the Los Angeles Aqueduct west of Salt Lake and El Paso, and south of Portland, was considered as local freight. The Southern Pacific Company also made Mojave, Lancaster, Saugus and Owens Valley stations on the Nevada and California (old narrow gauge) Railway, Pacific Coast terminal points for all transcontinental freight for the Los Angeles Aqueduct. The granting of these special freight rates meant the saving of many thousands of dollars on the construction of the Aqueduct.

Red Rock Railroad

The Red Rock Railroad was a branch line built from Cantil Siding, which is 23 miles north of Mojave, up the Red Rock Canyon to the line of the Aqueduct, a distance of nine miles. The freight carried over this road supplied the north end of the Jawbone division, and about 15 miles of the Freeman division. The road was built because of the exceedingly sandy character of the wagon road in the canyon, which made the hauling of freight on wagons almost prohibitive.

A contract was made with the Southern Pacific Company in September, 1908, for the construction of this road. It provided that material for the building of the road should be sold at cost, but that grading and bridge work should be done at cost plus 10 per cent. It also contained a provision for the sale of all salvaged materials, when the road was dismantled, the prices to be subject to arbitration.

The road was completed in January, 1909, and was operated continuously for 22 months thereafter. It was dismantled in December, 1910, by the Southern Pacific Company, and the material sold to the railroad company and the U. S. Reclamation Service for approximately $40,000.00, which is about 65 per cent of the original invoice value of the track materials.

The net cost of the railroad to the city, including $15,000.00 for repairs, following a severe washout, and loss on rolling stock, was $96,810. The cost of operating the road which was on an average grade of 3.4 per cent, was 8 cents per ton-mile, and the total cost for handling 45,059 tons of freight, including washout repairs, dismantling, equipment loss and construction and depreciation charges, was 33.7 cents per ton-mile. Of this amount 20.3 cents per ton-mile was charged for depreciation and construction charges. To have moved this tonnage up the Red Rock Canyon by means of teams would have cost about 50 cents per ton-mile, and at least $15,000.00 would have had to be spent on the wagon road to put it in even fair condition. The cost per ton-mile for operating the road was high, because of the shortness of the haul, the unavoidably heavy grades and the low tonnage which was transported.

Traction Engines

Despite the building of the railroads, an enormous amount of hauling was necessary

CONSTRUCTION CAMP IN WATE R CANYON, JAWBONE DIVISION

COTTONWOOD POWER HOUSE

from railroad stations to the various points along the line, and particularly for the portion of the line west of Mojave in what is known as the Antelope Valley. In the Jawbone division, there were well-graded mountain roads, but in the Freeman division and the Antelope Valley, the roads were adapted to a high efficiency for all kinds of wagon hauling. The transportation problem was one of the most serious in the work, on account of the volume of freight, the absence of water in the country, and the long distances.

A type of traction engine had been developed in California known as the "Caterpillar," which has a broad continuous track, running over sprocket wheels in such a manner as to give a wide bearing surface and great traction power. One steamer and two gasoline engines of this type were purchased for experimental work on the Jawbone division. The manufacturers placed an expert mechanic in charge of them, and a trial of two or three months' duration was made, under varying conditions of road bed and gradients. At the same time bids were called for for the transportation of freight over these roads by teams. The best bids were 40 cents per ton-mile. The traction engines on this trial materially bettered these figures. They were especially efficient in hauling heavy loads. Because of this apparent success of the traction engine, additional machines of this type were purchased, until 28 in all were obtained. The traction engines, when new, showed a substantial economy over the contract team transportation.

Reduced Efficiency of Engines

As the work proceeded, two things developed; first, as the traction engines became old, the number of breakdowns greatly increased and the corresponding cost of repairs ran up; second, it was found by experience that by purchasing live stock and wagons and thoroughly organizing the wagon transportation, the figures bid by contractors could be reduced. Teams of from 10 to 14 animals were handled by one driver and hitched to from two to three heavy wagons. On the desert roads a ton could be hauled to the animal and 20 miles could be covered by a team in one day. This made the cost for team hauling with city stock about one-half the price bid by contractors, or between 12 and 13 cents per ton-mile. These two conditions operated to the disadvantage of the traction engine and resulted in its condemnation as a means of transportation. While the engine could be operated at as low a cost per ton-mile as the team, the cost of repairs was as great per ton-mile as the operating cost.

Caterpillars Abandoned

Every effort was made to improve on these conditions. Patterns were obtained for nearly all parts of the engine, castings were made in local shops at low cost, and all machine work was done at the City shops in Mojave. Despite these efforts, the repair bills on the engines were practically prohibitive. After an earnest effort to make a success of these engines, they were finally abandoned and the gas engines taken therefrom for use in places where gasoline power was desirable. The frame work of some of the engines was used for steel forms for concrete work, and some of the "caterpillars" were sold to private parties for farming purposes. They were the only type of equipment that was purchased in the building of the Aqueduct that was unsatisfactory. In contrast with these disappointing traction engine experiences, the wagon haul record that was made by the Aqueduct organization was satisfactory. Large quantities of material were hauled over the desert roads at prices ranging from 12 to 15 cents per ton-mile, and over the mountainous divisions, where the roads were crooked and the grades ranged from 5 to 7 per cent, the hauling charges varied from 25 to 35 cents per ton-mile.

CEMENT MILL AND TUFA PLANTS

In June, 1907, bids were received on one and a quarter million barrels of cement from the larger cement manufacturers throughout the state, the lowest bid being $1.65½ delivered at Mojave. Investigations had already been made as to the advisability of the City building its own mill at Monolith, where there is a large supply of suitable clay and limestone. Estimates made by E. Duryee, cement expert, showed that a Portland cement could be made at a cost that would represent a saving, in view of the bids, to the City. Basing their decision on these investigations, the Board of Public Works authorized the construction of the cement mill at Monolith.

Monolith is located on the Valley line of the Southern Pacific about 15 miles northwest of Mojave. It is centrally located as regards the Aqueduct line, thus saving considerably in freight charges.

Material for Cement Making

The City owns three limestone properties: 1. The Cuddeback Ledge on a 160-acre tract, purchased from John Cuddeback, three miles west of the mill; 2. The North Quarry on a tract of 640 acres, five and one-half miles northwest of the mill; 3. The South Quarry on a tract of 120 acres, situated six miles southwest of the mill. When the mill was started, the title to the Cuddeback Quarry was contested, and the South Quarry was necessarily opened first. An aerial tramway 4,700 feet long, and with a carrying capacity of 30 tons per hour, was installed, and delivered limestone to a bin, having a capacity of 250 tons, near the base of the hill. A narrow gauge railroad was built from this bin to the mill, a distance of 5¼ miles.

The limestone is of suitable quality for cement manufacture, as shown by the following analyses:

ANALYSES OF LIMESTONE

	A %	B %	C %	D %	E %	F %
Silica	00.451	00.75	1.90	1.30	1.00	1.45
Alumina and Ferric Oxide	.500	.60	.75	3.00	1.10	1.35
Carbonate of Lime	98.250	97.86	96.43	94.46	97.00	96.25
Carbonate of Magnesia	.490	00.15	0.98*	0.984	1.36	.675
	99.691	99.36	100.96	99.744	100.46	99.72

Analysis "A" is of rock from the South Quarry. Analyses "B", "C", "D", "E" and "F" are from the Cuddeback Quarry.

Clay is obtained from the bed of a shallow lake of 320 acres adjoining the mill. Title was obtained to this deposit from the government by a special act of Congress, as well as by the purchase of riparian lands. Inasmuch as the lake is shallow and the quantity of water small, the best method of procuring this clay was to drain the lake in the spring after the rainy season, and excavate enough material in the summer months, while the lake bed is dry, to provide for the entire year. The clay is transported to the mill by an aerial tramway 5,800 feet long, with a carrying capacity of 25 tons per hour. In the rear of the mill a storage floor for a six months supply of clay has been provided.

The following are analyses of samples of clay taken at different depths in the bed:

ANALYSES OF TEHACHAPI LAKE CLAY

	Surface %	2 ft. feet deep %	8 to 12 feet deep %	14 to 20 feet deep %	24 feet deep %	Mixed Sample %
Silica	47.05	47.40	54.10	56.52	53.91	51.35
Alumina	12.38)					
	)	19.20	23.41	24.71	20.20	26.40
Ferric Oxide	5.57)					
Lime	8.95	6.00	5.61	5.00	6.32	4.55
Magnesia	4.74	3.26	1.04	.61	3.38	1.17
Ignition Losses	17.51	17.10	14.70	11.70	15.40	16.30
	19.20	92.96	98.86	98.54	99.11	99.77

CITY'S CEMENT MILL AT MONOLITH

Large deposits of tufa rock are available within a few hundred feet of the mill, which may be used in the production of a tufa cement. Very little tufa cement was manufactured at this mill.

Description of Mill at Monolith

The mill has a daily capacity of 1200 barrels of Portland cement. The raw end of the mill is equipped with the following:

1—No. 6 McCully gyratory crusher,
2—Vulcan Iron Works dryers,
3—No. 8 Krupp ball mills,
5—6′ x 16′ Krupp tube mills,
1—42″ Lehigh-Fuller mill,
with the necessary elevators, conveyors, scales, etc.

The burning department is equipped with the following:

3—90″ x 125′ rotary kilns, with rotary coolers, all built by the Vulcan Iron Works of Wilkesbarre, Penn.
Pivoted bucket conveyors built by Webster Manufacturing Company.

The finish end of the mill is equipped as follows:

3—No. 8 Krupp ball mills,
5—5′ x 16′ Krupp tube mills,

with necessary elevators, conveyors, scales, etc.

The tufa regrinding plant is equipped with the following:

1—No. 8 Gates ball mill,
1—5′ x 16′ Gates tube mill,
2—5′ 6″ x 20′ 0″ Gates tube mills,
1—Tufa rock dryer,

With crushers, conveyors, etc.

The No. 8 ball mill, the 6′ x 16′ tube mill and the two 5′ 6″ x 20′ 0″ Gates tube mills, listed under the tufa regrinding plant, can also be used in connection with the finishing end of the main plant to augment the output of straight cement if necessary.

The mill throughout is fitted up with independent motor drives to the different pieces of machinery. It is all of steel construction, covered with galvanized corrugated iron. The stock house is divided into six separate bins, having a total storage capacity of 24,000 barrels. It is fitted up with the necessary screw conveyors and automatic weighing machines, and is so situated that cement may be loaded directly into railroad cars, or stored in an adjacent warehouse.

The power plant consists of the following:

2—500 horse power Keewanee water tube boilers,
2—250 horse power Keewanee water tube boilers,
2—Curtiss turbines—750 K.W. each.
Tubular condensors; water, air feed and oil pumps; exciter engines; water heaters; water cooling ponds; switch board.

It is also equipped with the necessary connections and transformers to use high tension current from the Aqueduct hydro-electric plant.

The camp at the mill developed into a small town. In addition to the mill buildings proper there are 38 buildings consisting of the following:

21 dwellings of from 1 to 6 rooms each.
6 frame tent houses.
7 bunk houses to accommodate 130 men.
1 school house.
1 mess hall and kitchen.
1 hospital building.
1 general merchandise store.

All the buildings, except the store, were erected and are owned by the City. Streets were surveyed, and sewer and domestic water systems were installed. An abundant supply of excellent artesian water was secured at a depth of 120 feet. The water is pumped into a concrete reservoir of 100,000 gallons capacity, located on a terrace above the town and mill sites, and provides adequate pressure for fire protection.

Quality of Cement

More than 900,000 barrels of cement were produced by the City at the Monolith plant, under the brand name of "Monolith." The product has been a very satisfactory, standard hydraulic Portland cement. The manufacture of cement is a combined physical and chemical process, the highest authorities agreeing that there is no hard and fast rule which will govern all possible contingencies, and each new

mill has to work out its local problems. These were mastered in the case of the Monolith mill, not without some difficulties. For instance, because of certain legal conditions, the quarry, which was intended to be used for the mill, could not at first be opened up and a more remote deposit of limestone was utilized. When the change was made from the old quarry to the new, it was necessary to again adjust for the new limestone, which took some 30 days time, during which some of the cement had to be condemned. These were incidents rather than prevailing conditions at the mill, and they occur in all cement mills. When the City purchased cement from other mills, the product was rigidly inspected and some rejections were made as the result of laboratory tests.

The California cement manufacturers were in a close combine, and they resented the municipal manufacture of a cement, in the same way in which they resented the federal manufacture of cement at the Roosevelt Dam. The product of the mill was watched by them closely, especially when any of it was shipped into the City of Los Angeles. On the occasion when the lime quarries were being changed and difficulty was being experienced, a committee of engineers, employed by the American Association of Portland Cement Manufacturers, promptly appeared and demanded samples from the mill for the purpose of test. They also made this the occasion for a criticism of a portion of the concrete work of the Aqueduct, asserting that the points selected were examples of the poor work due to a municipally manufactured cement. The fact was that the majority of the work so criticised was built of cement purchased from other plants.

The Board of Public Works never thought that it could make either better cement or cheaper cement than existing plants in California, but it was led to believe, from bids that had been submitted and from prices paid by the City for cement for other public work, that the City could manufacture cement cheaper than the association mills would sell it to the Board. After the City had constructed its mill, it was quite possible for it to purchase cement at prices lower than the ordinary market rates, and it appeared that some of the manufacturers were pleased to sell cement at a figure a shade lower than the City could manufacture it.

Unlimited strength, curves and tests could be given, showing the quality of the City's cement. Its uniformity in attaining a final high tensile strength has been one of its greatest recommendations. This is due to the fact that the raw deposits are very large and uniform. Very little free lime was ever found in the cement, and none whatever in that portion which was combined with tufa. The cement has an unusual toughness, which has had much to do with the success experienced in the building of the Aqueduct with it. The quality of the cement, as a whole, is not only proved by the laboratory tests, but also by the excellent showing in the building of the Aqueduct, where first-class rock, gravel and sand were not always available. The effort was made to produce a concrete that was good enough, rather than to set a fixed standard of a rigid character for graded materials. The amount of cement used was varied with the character of the aggregates with which it had to be combined, economy, with reasonable strength, being the basis of judgment. Below is a series of tests, which are the average for a multitude of samples from the Monolith plant:

TENSILE STRENGTHS OF MONOLITH PORTLAND CEMENT

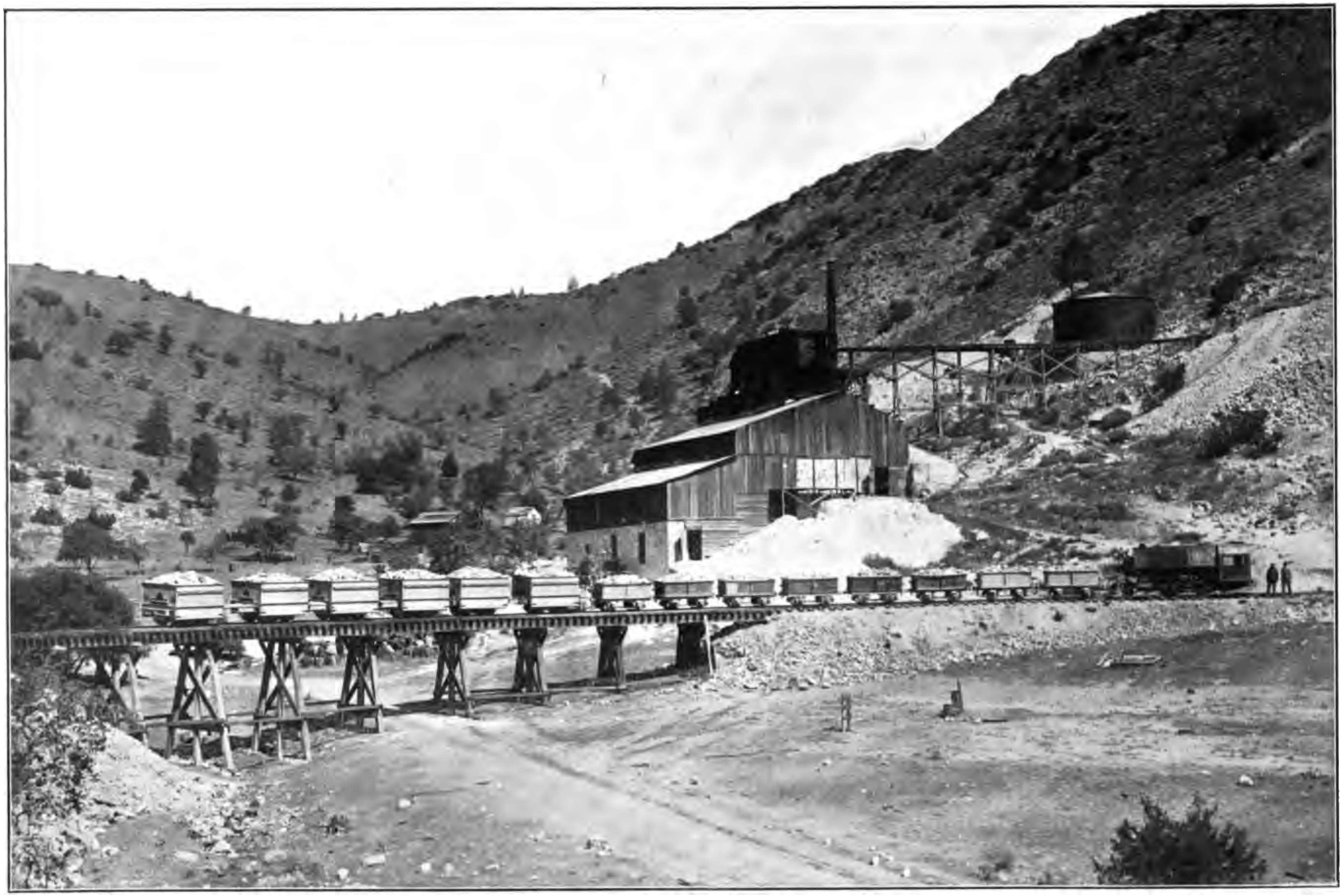
Mixture 1 cement to 3 of sand

3 days	7 days	28 days	3 mo.	6 mo.	1 year	2 years	Fineness
150	205	310	375	440	500	580	
150	215	300	380	410	445	595	93—100 mesh
190	265	400	460	460	525	605	

CHEMICAL ANALYSIS OF MONOLITH PORTLAND CEMENT

SiO_2	22.22	Specific Gravity	3.13
R_2O_3	9.85	Setting time:	
CaO	64.85	Initial	2 hrs. 50 min.
MgO	2.24	Final	6 hrs. 40 min.
SO_3	1.45	Boiling Test	O.K. 6 hrs.

$R_2O_3 = Fe_2O_3 + Al_2O_3$.



TRAIN HANDLING LIMESTONE TO MONOLITH

A good deal of Monolith cement has been used in the various departments of the City government. A grandstand has been built of reinforced beam and thin slab construction for the Park Department. The architects having charge of this work insisted on very rigid tests being made of this cement. Samples were taken by the Architect and submitted to a local testing firm to determine their characteristics. In the table given above, their results are compared with the requirements of the American Society for the Testing of Materials, and with the new specifications of the United States Bureau of Standards:

PHYSICAL TESTS OF MONOLITH CEMENT

Authority	Pounds per sq. in. in Tensile Strength — Neat Pure — 1 day	7 days	28 days	1 part cement, 3 pts. sand — 7 days	28 days
Am. Soc. Test Materials Specification	175	500	600	200	275
U. S. Bureau of Standards Specifications	None	500	600	200	275
Smith Emery Co. Test	182	632	798	202	273
	244	656	838	215	280
	216	709	800	214	285

CHEMICAL TESTS OF MONOLITH CEMENT

	U. S. Bureau Standard Specifications Per Cent.	American Society Test Materials	Smith Emery Co. Tests Per Cent. No. 1	No. 2	No. 3
Silica	19 to 25		25.02	24.72	24.80
Alumina	5 to 9		5.58	5.40	5.52
Iron Oxide	2 to 4		2.72	2.00	2.48
Lime	60 to 64		62.70	63.20	62.92
Magnesia	1 to 4	Not over 4	1.76	1.98	1.66
Sulphur Trioxide	1 to 1.75	Not over 1.75	1.14	.95	1.08
Loss on Ignition	0.5 to 3.0		1.80	2.00	2.00
Insoluble residue	0.1 to 1.0		....	....	....
Fineness through 200 Mesh	75% or over	75% or over	81.2	80.4	80.8
Fineness through 100 Mesh	92% or over	92% or over	94.	94.	94.2
Setting Time	Not less than 45 minutes	Not less than 30 minutes	3 hrs.	3 hrs.	3 hrs.
Boiling Test	Boil without cracking	Boil without cracking	O. K.	O. K.	O. K.
Specific Gravity	Not less than 3.10	Not less than 3.10	3.12	3.12	3.12

NOTE—The ratio of the weight of Aluminum Silicate to that of the lime is called the Hydraulic Index and should show as high as 1.91, the German cements showing 1.98. The above analysis indicates for Monolith cement 2.08.

Tufa Cement

In the early stages of the work on the Aqueduct, a number of deposits of volcanic tufa were found, which closely resemble, chemically and physically, the German Trass and the Italian Pussuolana. Two deposits, one at Haiwee and the other at Fairmont, situated at remote points on the work, where transportation charges were especially high, were opened, and regrinding plants constructed for the purpose of blending these volcanic products with straight Portland cement, producing what has been called a Tufa Cement, and thus effecting an economy of approximately $1.00 a barrel without decreasing the quality of the product.

This process was extensively described by J. B. Lippincott, Assistant Chief Engineer, in a contribution to the American Society of Civil Engineers, published in the Transactions of the Society in Volume LXXVI, page 520, in the year 1913. The process is also described

in detail in the Seventh Annual Report of the Los Angeles Aqueduct.

The Haiwee plant is situated 120 miles north, by rail, from Monolith, and the Fairmont plant is in the west end of the Antelope Valley, 20 miles from the railroad, southwest from Mojave. The cost of the Fairmont regrinding plant was $27,000.00.

It was found that these tufas could be blended successfully with the Monolith cement or with other brands of commercial cement. Tufa is an indurated soft volcanic ash product, pumiceous in texture. It was first run through a jaw crusher and broken to 1½-inch size. It was then carried to a No. 8 Krupp ball mill, where it was ground to pass through a 20-mesh screen, or finer. This ground tufa was then blended in equal parts by volume with standard hydraulic cement. This blend was then conveyed to a Gates tube mill, 6 by 16 feet in size, and the tufa and cement ground together to a fineness of 90 per cent. or more, passing through a 200-mesh sieve. At the Fairmont mill it was found that, under natural conditions, from 1,200 to 1,500 sacks of tufa cement could be ground per 24 hours. By arranging crude drying devices and driving off the moisture in the tufa, this output was increased to from 1,800 to 2,000 sacks per day.

The chemical analyses of the tufa show a striking resemblance to the German Trass, which is used extensively in this manner on the continent. It uniformly stands the boiling test, which indicates the chemical combination of the finely ground tufa with any excess lime in the hydraulic cement. The following table shows the physical tests of a great number of samples of tufa cement, mixed with sand in the ratio of 1 to 3, broken at the Fairmont and Haiwee mills:

PHYSICAL TESTS OF FAIRMONT AND HAIWEE TUFA CEMENTS

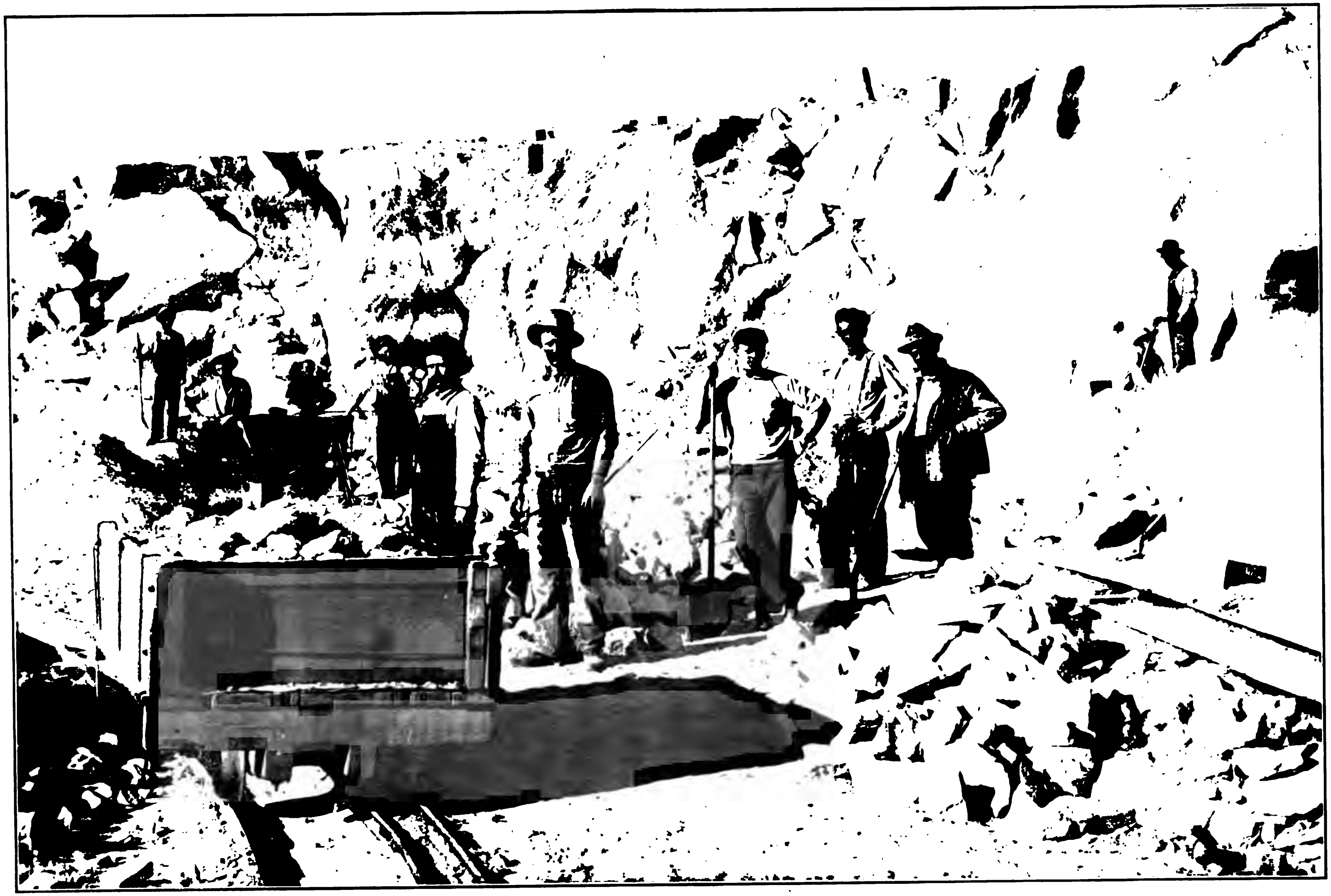
3 days	7 days	28 days	3 mo.	6 mo.	1 year	2 years	Fineness
Fairmont Tufa Cement							
160	280	445	465	535	550	610	
190	300	425	510	560	560	670	91—200 Mesh
160	305	440	550	575	620	675	
Haiwee Tufa Cement							
180	235	395	480	500	520	600	
165	255	375	445	490	500	605	91—200 Mesh
170	220	375	450	595	595	650	

The distinctive feature of this tufa cement is its continued growth in strength with age. Up to seven days, the tufa samples usually show less strength than the straight cement, when mixed with sand, but after this time they usually show greater strength, and at the end of the two-year period are nearly always stronger. The characteristic of the tufa cement is that it is not so hard, but that it is tougher. It has to be handled with greater care than ordinary cement, and because of this slower hardening is more likely to be affected by extremes of temperature while setting. Because of its finer grinding, it makes a denser concrete. Most of the concrete siphons on the Aqueduct are made of tufa cement.

One of the peculiarities of the tufa cement is that larger amounts of tufa than 50 per cent. can be added without seriously interfering with its ultimate strength. Careful tests, made both by the laboratories of the City and by Government laboratories, show that the tufa combines chemically as well as mechanically with hydraulic cement. A test run of 80 per cent. tufa and 20 per cent. hydraulic cement gave a strength of 20 pounds in three days, 75 pounds in seven days, 155 pounds in three months, and 300 pounds in six months. For the purpose of testing these leaner mixes in actual construction, a mill run of 100 barrels was made at Haiwee of 75 per cent. tufa and 25 per cent. hydraulic cement, and put in 100 feet of the lining of the open Aqueduct north of the Haiwee reservoir to compare with the 50 per cent. blends that were adopted as standard. Little difference could be distinguished between the two concretes in the work itself. This indicates that a lean cement of this nature, which would be impervious to water, could be successfully used in the lining of open irrigation canals.

Slab Tests

Many tests were made of slabs constructed of the tufa cement, which were loaded to de-



TUFA QUARRY AT FAIRMONT

struction. The tufa cement showed better results than slabs made with the straight hydraulic cement. The tufa cement has greater flexibility. It shows greater strength and better results than "silica cement." The Los Angeles Aqueduct engineers did pioneer work in the making of tufa cement in this country. The tests made on the Aqueduct are entirely in harmony with those made by the German government on the German Trass cements, as shown in the detailed descriptions of the tufa cements referred to above. Similar results are obtained in Italy.

The average cost of blending one barrel of straight cement so as to produce two barrels of tufa cement, with the small mills installed on the Los Angeles Aqueduct, was about 74 cents for the two barrels of the blend, or 37 cents per barrel of tufa cement. These costs are made up as follows:

General expense, labor, livestock, etc.	$ .04
Electric power at 1.85 cts. per kilowatt hour	.105
Quarrying	.025
Mill Operations	.20
Net Milling Cost	.37

The process of blending one barrel of straight cement with an equal part by volume of tufa cement gives a resulting product 10 per cent. by volume in excess of the two barrels of tufa cement. The weight of a sack of tufa cement was accepted as 83 pounds.

Tufa Concrete

In conclusion it may be stated that tufa, when finely ground with cement, and used in concrete, combines both chemically and mechanically; blends of 50 per cent, when mixed with sand, give greater tensile strengths, after 10 days, than straight cement mixed with the same proportion of sand; the leaner the mixture, the greater the relative superiority of the tufa cement; in compression, the tufa cement concrete is about 20 per cent. less strong in richer mixtures of 1-2-4, and as strong in leaner mixtures of 1-3-6; tufa cements in tension show a continued growth in strength with age up to five years, and in this respect are superior to straight cements, which usually show declining strengths. Tufa concretes must be handled with greater care with reference to both cold and drying, and forms should be left in place about one-third longer. In massive work this feature is negligible. From the fact that the tufa cement is more finely ground, and, in part combines mechanically with other aggregates, carrying the gradation of fineness one step further, it makes a denser and more impervious concrete. Where cements are high-priced, a substantial economy may be effected if deposits of tufa are available and large quantities are to be used. The milling cost of producing the extra barrel of tufa cement in small plants should not exceed 75 cents.

Operating Costs

About 900,000 barrels of cement were produced by the Monolith mill. On an average, the operating costs of the mill have not been as low as was originally estimated, but on the whole were satisfactory. The cost sheets show that when the mill was running full capacity cement was produced, sacked and loaded on the cars at Monolith for $1.15 to $1.20 per barrel, exclusive of interest and depreciation.

The operation of this mill by the City was subject to certain disadvantages, among them being the necessary intermittent operation, due to the varying demand upon it by the Aqueduct construction; also the fact that the City must, under the law, operate on an eight-hour basis. This required it to pay for three full eight-hour shifts of labor in order to produce approximately the same amount of cement that a privately owned mill could produce with two 10-hour shifts. After the steam electric power plant at the mill had been built and put in operation, it was found that there was at times surplus power available from the City's hydro-electric plant at Cottonwood, and also that at other times the demand for power for construction purposes on the Cottonwood plant was more than it could meet. The transmission line from Cottonwood was extended to Monolith and the two plants operated in parallel. This condition, while to some extent advantageous to the mill, operated against it,

as when the demand for power for construction purposes was greater than the capacity of the Cottonwood plant, the surplus was drawn from the cement mill. This caused temporary delays at the mill, but these were overbalanced by the increased efficiency in the Aqueduct construction. Under this arrangement the cost of power alone was about 25 cents per barrel. This item could be materially reduced by connecting the mill with a hydro-electric plant where a steady load could be assured and energy delivered at a reasonable rate.

Cement Purchased

During the time the work was going at maximum speed in 1910, the consumption of cement was about 1,600 barrels a day, which was more than the output of the City's mill, and it became necessary to provide additional cement or reduce the rate of progress. Consequently, during the early spring of 1910, a contract was entered into with the Riverside Portland Cement Company for the purchase of 100,000 barrels of cement, with an option on 100,000 barrels more, at a price amounting to $1.43 per barrel, delivered at Mojave. Subsequently the right to purchase the second 100,000 barrels under the option was exercised. This was the first sale of cement from the Riverside mill, and the price was materially lower than that which prevailed in the local market. It was doubtless affected also by the fact that the City was in possession of a mill.

On account of the general financial condition of the country in the spring of 1910, the firm purchasing the Aqueduct bonds did not advance money as rapidly as was expected by the Board of Public Works, and it became necessary to greatly reduce the monthly expenditure. This reduced the cement consumption, and as the contract with the cement company was in force, its cement had to be taken, and it became necessary to temporarily close down the mill. This shut-down was taken advantage of to make a number of adjustments in the machinery and some general change in the lay-out of the plant. These changes, with the experience gained in operation, proved advantageous in that the quality as well as the quantity of cement produced was augmented. The title of the Cuddeback Quarry was cleared, and in the spring of 1912 that quarry was opened and a railroad built to the mill. The quarry is much larger than the south quarry; it has unlimited quantities of good limestone and the distance to the mill is but half that of the south quarry.

ENGINEERING DESCRIPTION OF DAMS AND HYDRAULIC PROCESS OF CONSTRUCTION

Geologic and Topographic Features of Reservoir Sites

Headworks

As the Owens River is a stream that is fed by the melting snow in the mountains, rather than immediately by the rains, it is not subject to such violent floods as are characteristic of many other streams in the West. Consequently the headworks on this stream do not have to be built for a great flood discharge. The maximum flood observed since 1904 was 2,610 second feet. The bed of the stream consists of a covering of sand on a blue clay and silt. The banks are largely clay with a mat of sod. Immediately below the intake of the canal it passes through a deep cut through a low hill.

The intake of the Aqueduct consists of a diversion weir and sluiceway 325 feet long, and four control gates at the head of the canal.* There are three radial sluice gates at each end of the diversion weir, 8 feet wide and 8½ feet high. They are built upon steel sheet piling and concrete, with concrete abutments. These gates may be opened to pass unusual floods or to sluice out the river channel immediately in front of the intake of the canal. Between these gates are 240 feet of overflow weir. The weir consists of a reinforced concrete apron, upon which are built concrete abutments supporting vertical reinforced concrete walls. The abutments extend above the walls, flash boards being provided by which the water level can be raised an additional two feet. Sheet steel piling is driven 20 feet into the sand and clay formation on the upstream and downstream sides to prevent underflow, and this piling is extended 75 feet to high ground on the east bank and into the canal bank on the west. The lower toe of the weir is protected from the back-lash of the water, or undercutting, by heavy rubble pitching. Soundings have been taken on this lower toe and riprap added until its stability has been established. There are four control gates at the intake of the canal. These also are of the radial type, 8 feet wide and 7 feet high. All of these gates were built at Aqueduct shops. They work satisfactorily and are tight. A rubber belt gasket is used on the side of the gate to prevent leakage. The operation of either the river or canal gates will permit of the regulation of the inflow to the canal. The total cost of the headworks complete, including the canal regulating gates, was $63,447.68.

The features of this headworks control are its simplicity and its cheapness.* The structure has withstood the largest flood that has been measured in the river since records began. When the regulating gate in the canal was being built, this maximum flood of 2,610 second feet overtopped the partially finished green concrete and caused some failure to the side walls, but this was repaired at slight expense. The $63,447.68 includes the replacements that were made.

The river carries a very low percentage of silt, and has no drifting sand bars. It is well confined in its natural banks, and the growth of trees along the channel indicates its permanence.

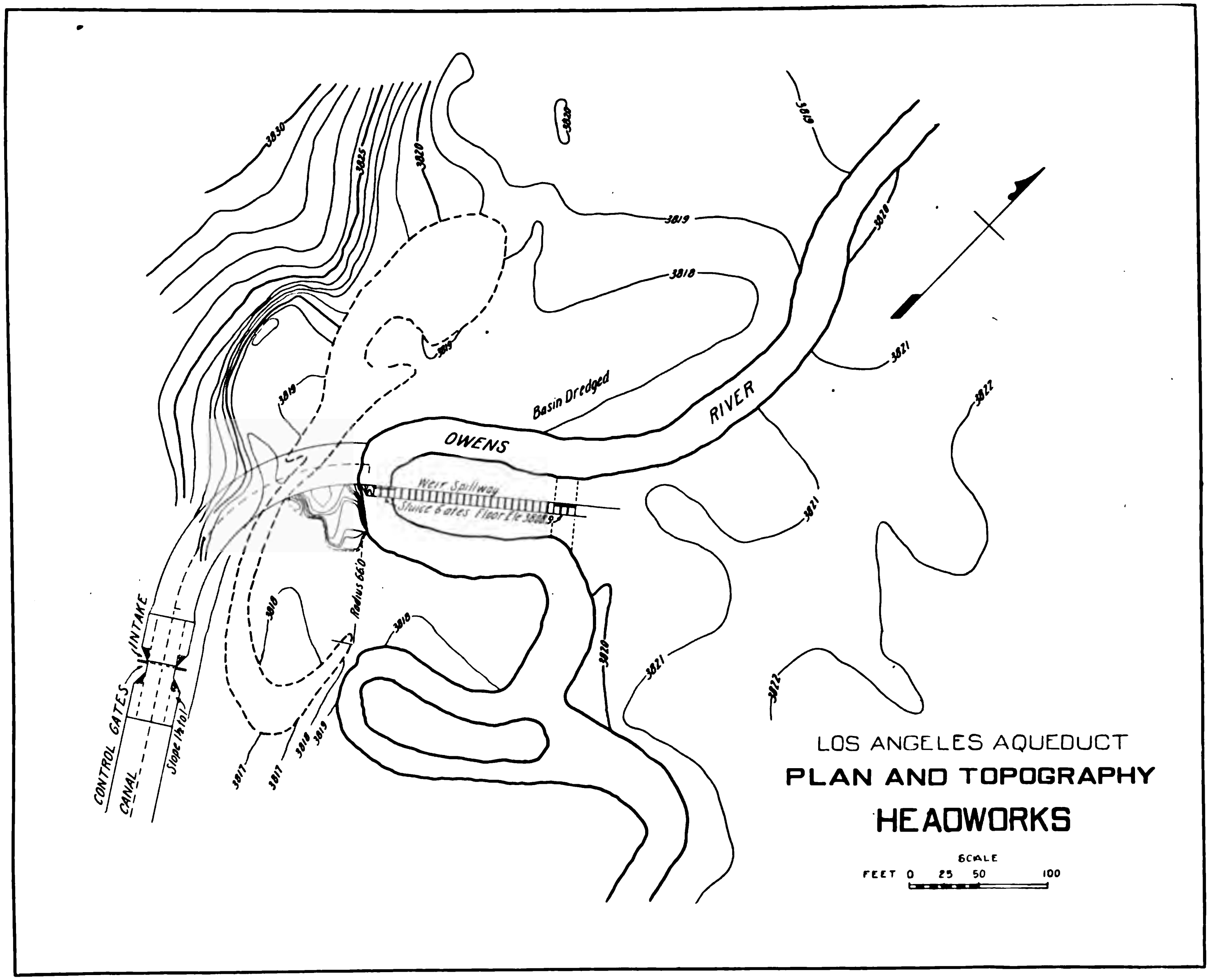
The headworks of irrigation structures of the farming communities in the valley are very frail affairs consisting of light wooden structures, that are braced with loose rock filling, and yet they serve their purpose fairly well, showing an absence of destructive violence in the stream floods.

Haiwee Reservoir

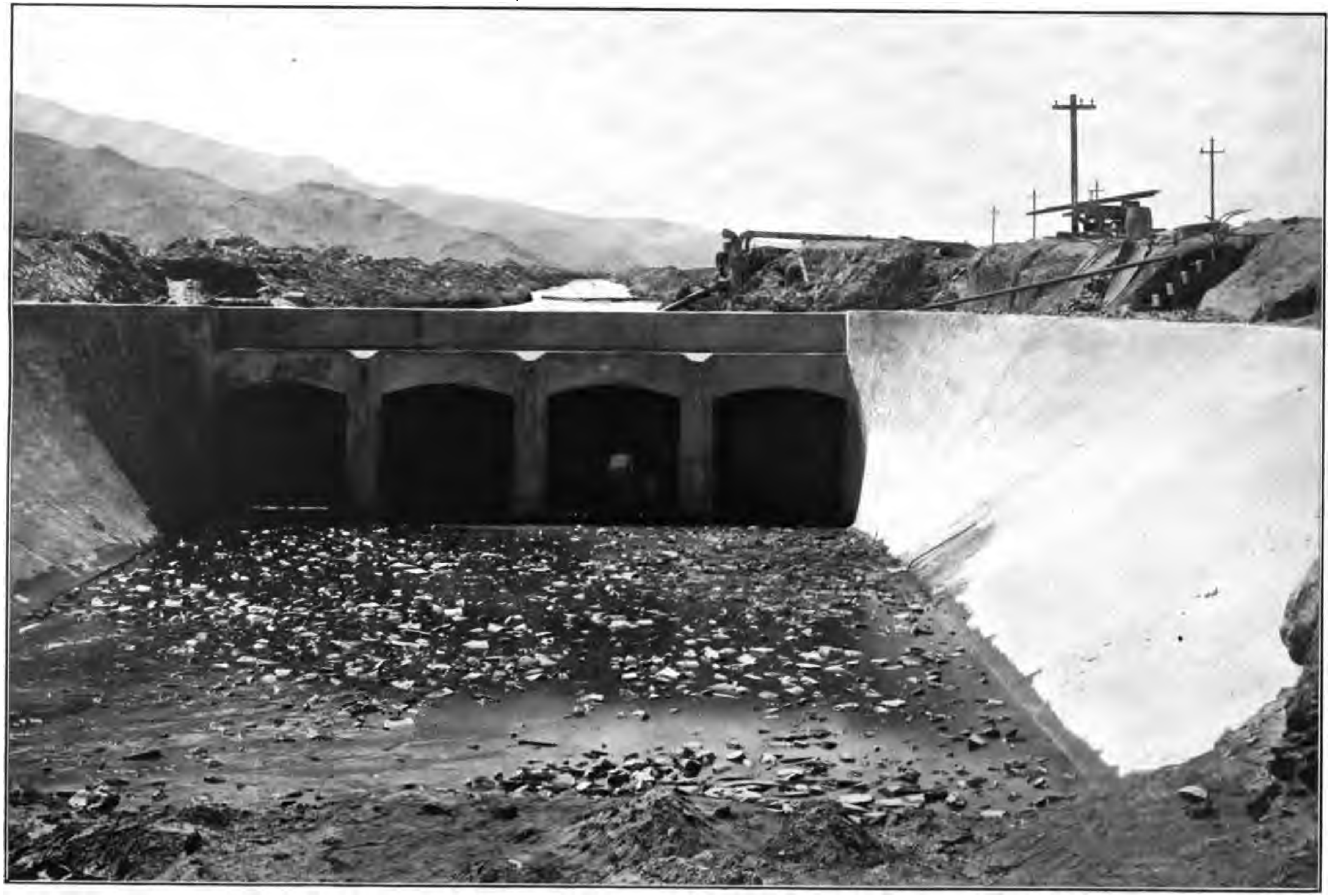
The Haiwee reservoir is situated in a summit valley, the southern portion of which drains to the south towards the Mojave Des-

*See Plate No. 9. Plan and Cross Section of Headworks—in map pocket.

**See Plate No. 10. Plan and Cross Section of Intake Control Gates—in map pocket.



MAP SHOWING LOCATION OF HEADWORKS WITH REFERENCE TO OWENS RIVER



CONSTRUCTION OF INTAKE GATE

ert, and the northern portion of which drains towards Owens Lake. In previous geological times, when the lake was much greater than at present, this place was the outlet of the Owens River drainage basin toards the south.

The Haiwee Reservoir site occupies a remnant of the eroded valley of the greater Owens River of glacial times, a time when the flow was greater than the present by reason not alone of the greater precipitation, but the very much larger area drained, as the evidence is very complete that the Mono Basin overflowed into the Owens Valley as shown by the high lake terraces, plainly defined, of the Mono Lake Basin.*

The bedrock underlying the Haiwee Reservoir site consists of an unaltered shale deposit, having a dip of 10° westward. These shales are somewhat interbedded with thin layers of fine-grained friable sandstone, but feebly lithified. Borings at the north and south Haiwee dams, down to and into the shale, disclosed the fact that at the deepest depression of erosion the ancient river had a fall of about eight feet to the mile and had cut its way down in this stratified formation to a depth of 100 to 150 feet.

The out-wash slopes of the Sierra Nevadas, which lie to the west a distance of about four miles and paralleling the Haiwee Basin depression, terminate at the side of the basin and are in some places truncated so as to show a depth overlying the shale of 40 or 50 feet, consisting exclusively of granitic bowlders and gravel. The east side of the basin is a portion of the Coso Mountains which are heavily lava-capped, the summit of the cap consisting of heavy basalt lavas overlaying beds of pumiceous material of great thickness.

The deep cut of the river through this region in the weak shale formation induced some heavy displacements by land-slip from both sides of the basin so that the perimeter of the reservoir, especially in its lower reach, presents a sinuous and deeply indented shore line, with the displaced masses standing out prominently in peninsular form.

With the cessation of the flow of the river through this valley the depression was partly filled up with debris brought down evidently by the torrential cloud-burst precipitations so common in arid regions such as this.

The occurrence of two ravines facing each other, one from the east and the other from the west, near the middle of the basin filled it up at this point about to the high-water level of the reservoir. This obstruction had to be cut through to a depth of 15 feet, after which the cut was widened and deepened by permitting the flow of the Aqueduct to pass through it, holding the lower basin depressed meanwhile. This proceeding was effective until the bottom of the cut became paved with the accumulating bowlders existing in the debris, and since the channel is still not deep enough to enable the complete utilization and drainage of the upper basin it will be necessary to dredge it still deeper to remove the accumulation of these bowlders.

North Dyke

Two dams are necessary to enclose this reservoir; the small dam known as the North Haiwee Dyke,** and the southern dam known as the South Haiwee Dam. Because of the very low head of water against the North Dyke, this structure was not connected with bed rock, which is some 120 feet deep. It is considered rather a levee than a dam. A cut approximately 12 feet in depth was made with a steam shovel through the divide between the two ends of this reservoir. This cut was closed with a small temporary dam and the north end of the reservoir filled until the temporary dam was overtopped, the idea being to deepen this cut by sluicing water through the opening. In this way the cut was gradually deepened. It was contemplated at one time that the maximum water level in the Haiwee Reservoir might be raised five feet. This would increase the storage capacity 11,000 acre feet. The gradient of the canal north of the reservoir is rigidly fixed so that it could not be altered, and it is the plan, if the water level in the reservoir ever should be raised, to raise also the sides of the canal sufficiently to provide for this increased elevation. It is doubtful whether this will ever be done, be-

*See Plate No. 11. Map of Haiwee Reservoir—in map pocket.

**See Plate No. 12. Plan and Cross Section North Haiwee Dam—in map pocket.

cause two large reservoir sites are available for use above the intake. They are the Long Valley reservoir site and the Tinemaha reservoir site. The North Haiwee Dyke, with this idea in view, has been given a very broad top, but the South Haiwee Dam has been built to the full elevation, which is 3,774 feet.

The length of the North Haiwee Dyke is 1,890 feet and the maximum height 34 feet. The maximum depth of water against the dyke will be 28 feet. The side slopes are 3 horizontal to 1 vertical on the water side, and 2½ horizontal to 1 vertical on the other side. The depth to bed rock is known to be about 120 feet at this point, the material on top being silt and fine sand. The cost of going down to bed rock with an impervious curtain wall at this dam would have been fully $70,000.00, which is what the cut-off wall of the South Dam cost. A shallow cut-off trench was made.

The dam was built in greater part by the hydraulic method. The waters of the Cottonwood Creek were run through the completed portion of the Aqueduct to the dam site, at which point they were picked up and discharged by a jetting pump of 100 pounds pressure per square inch through hydraulic nozzles against an earthen bank. The water and material thus washed down were run to a concrete sump, 10 feet in diameter, next picked up by a mud pump and discharged through a 12-inch pipe line to the dam. The jetting pump was of the centrifugal type with a 10-inch suction, and was driven with a 100 horse power motor. The mud pump, which was of the centrifugal type, had a 12-inch suction and was run with two 100 horse power motors. When it became necessary to discharge material at the far end of the dam, the load on the mud pumps became excessive, due largely to the high percentage of sand and silt carried by the water. A 10-inch centrifugal pump was then placed halfway along the force main as a booster pump, and successfully handled all the water that could be delivered to it from the 12-inch pump without a break in the force main. Electrical energy was furnished from the Aqueduct's hydraulic plant at Cottonwood.

The pipes delivering the silty water to the dam were discharged near the outer slopes, and it was found that a few workmen with shovels could keep the stream turned towards the center of the dam, thus avoiding the necessity of building up these slopes with teams. A pond was maintained in the center of the dam as it was raised in height, and the coarser materials of the water were deposited near the outside slopes and the finer materials were carried towards the center of the pond. An examination of the materials at different points in the dam indicated that there was a marked gradation of fineness towards the center. Before the dam was started, a drain pipe was laid at first towards the reservoir, from the center of the dam. This drain pipe, by means of a 90-degree ell, was brought up with the construction work by adding two-foot sections of pipe on its top as required. By this means the level of the water in the pond was kept at the required elevation.

Material for Fill

The first pit opened developed too much sand, which cut the pumps and the force mains in the most surprising manner; also it was not adapted to the carrying of high percentages of material in suspension by the water. For this reason it was abandoned and a second site selected near the east end of the dam, the plant being removed from its original site to the new point. The material in the second pits that were opened was much finer and lighter and moved much more rapidly. In October, 1912, 5,000 yards were moved from the first pit at a cost of 21.3 cents per cubic yard for field expenses, whereas the same equipment in the following month moved 48,000 yards from the new pit at a cost of 8.4 cents per cubic yard. This demonstrates the importance of obtaining a satisfactory bank to work in for hydraulic fill dams.

In building dams of this type, the volume of water determines the yardage of materials that can be deposited per day in a given structure, and much more can be accomplished with greater economy when large quantities, say as much as 10 cubic feet per second can be hand-

CONCRETE DIVERSION WEIR AT HEAD OF AQUEDUCT

led, than when smaller quantities are used. When a water supply is scarce, this condition can be remedied by draining the water, after it has been clarified, from the pond in the dam back to the sump, which is being drawn upon by the pumps; in this way using the water over and over again.

The work on North Haiwee Dyke was not started until late and was delayed by the cutting of the pumps with sand from the first pit. Partly for this reason a steam shovel was utilized for loading wagons, with which dirt was deposited at the west end of the dam. The haul with these wagons was from 200 to 500 feet, and the cost per cubic yard of material thus placed was between 25 and 30 cents. A large portion of the material thus placed in the dam was taken out of the channel of the inlet canal.

Inlet Canal

A great deal of consideration was given to the subject of how the water should be dropped from the hydraulic gradient of the canal into the upper end of the reservoir basin, which is a fall of some 30 feet. The inlet canal was lined with concrete to a point at which a cut-off wall was built about 10 feet deep below the bottom of the canal and 10 feet into the banks on either side. This inlet canal is in a cut with a maximum depth of about 30 feet. The material excavated consisted of sand, clay and bowlders. It was decided to let the water run free through this deep cut beyond the end of the concrete and make its own bed by washing boulders down from the sides into the bottom of the channel, just as a mountain stream will pave its own bed. This earthen canal was not taken down to sub-grade by from four to six feet.

The water side of the dam is paved with concrete to avoid wave erosion and to provide an impervious facing. The concrete is 8 inches thick and laid in articulated blocks 5 feet wide and 10 feet long, the joints being filled with asphaltum. The top and north sides of the dam are protected from the wind by gravel. Water enters the Haiwee reservoir at the west end of the North Dyke and is carried 1,200 feet beyond the dam and discharged into a ravine over the bowlder bed.

There is a total of 167,372 cubic yards of earth in this dam; 26,137 yards being placed by wagons and 141,235 cubic yards by the hydraulic process. The costs for this work are shown below. They include only the direct field charges, and do not include auxiliary expense, such as executive administration, equipment, etc. These auxiliary charges amount to 32½ per cent. for this type of construction:

COST OF NORTH HAIWEE DYKE

	Quantity Cu. Yds.	Total Cost	Unit Cost
Test shafts, etc.		$1,935.68	
Core wall trench	5,158	1,342.28	0.2604
Dry fill	26,137	7,185.82	.274
Installing hydraulic machinery	141,235	4,281.21	.0303
Sluicing	141,235	17,421.95	.123
Concreting face	3,215	17,323.16	5.39
Engineering	167,372	208.04	.0012
TOTAL		$49,698.14	

South Haiwee Dam*

At the location of the South Haiwee Dam, the bed rock is covered with a soil composed largely of sands and gravel derived from volcanic rocks. Three test wells were dug across the valley for the purpose of exploring the foundations. The soil stood up without timbering to depth of about 75 or 80 feet, where ground water was reached and had the appearance of being satisfactory to found a dam upon. A trench was then excavated with a power shovel to a depth of 14 feet on the axis of the dam, and the precaution was taken to fill this trench with water for the purpose of observing the action thereof.

This locality, while arid, is occasionally visited by severe storms of short duration, locally called cloudbursts, and the valley fill at this point apparently had been partly laid down by these sudden floods. A stream of one second foot of water was run into the trench. Within a week, settlements of the ground began, extending as much as 75 feet on each side of the

*See Plate No. 13. Plan of South Haiwee Dam—in map pocket.
See Plate No. 14. Profile and Cross Section South Haiwee Dam—in map pocket.

trench, the surface settling vertically as much as 12 inches, and opening cracks. This demonstrated the necessity of going to bed rock with a cut-off trench. The trench was extended entirely across the valley and reached a maximum depth of 120 feet. The material passed through consisted of fragmented volcanic material, except within two or three feet of the bottom, where a stratum of granitic sand and gravel was uncovered. The bed rock consisted of a dense tufa shale. The trench was excavated with light, stifflegged derricks carrying hoisting buckets, and the dump was removed with scrapers to the lower toe of the dam. Material removed from the trench measured 27,032 cubic yards; $22,422.00 was expended for labor, $2,280.00 for livestock, $1,843.00 for materials and supplies, $957.00 for electric energy, $630.00 for freight; the cost per cubic yard being $1.04. The entire trench had to be timbered, at a total cost of $41,391.00, of which $15,144.00 was for labor and $457.00 for live stock, or a cost per cubic yard excavated, of $1.53. The trench was filled with clay. The clay was loaded into dump wagons with an electric power shovel. The material was hauled a mean distance of 1,000 feet, dumped at the edge of the trench and pushed into it with a road grader. In this manner 27,032 yards were placed at a cost of 31½ cents per cubic yard. The trench was kept as nearly as possible full of water at the time the clay was going in, and the water raised as the fill came up. Observations on the material and its action in the trench indicated that the height of the clay wall resulted in its compacting itself with its own weight. Before filling the trench, experiments were made to test the percolation of water through clay under 100 feet of head, the clay diaphragm in the test being one inch thick, backed with sand on each side. Practically no percolation occurred. It is believed that this clay-filled trench is as impervious as a concrete wall, and it is far cheaper.

Hauling Material

An examination was made of the various soils suitable for dam building in this locality, and it was found that in a depression 1,000 feet north of the dam the valley fill consisted of a soil formed by the decomposition of tufa shale, containing over 35 per cent. of clay material, the balance consisting of granular material. A Model 60 Marion steam shovel was installed at this point; and a belt line railroad was constructed from the pit to the east end of the dam. The track divided at the east end of the dam, one branch passing over the north toe, and the other over the south toe, these branches reuniting at the west end of the dam and returning to the pit. Three trains were operated, each consisting of seven cars of four cubic yards capacity, or 28 cubic yards of loose materials per train. The pit measurements indicated that these cars actually hauled three yards of compact material. Each train was drawn by an 18-ton steam locomotive manufactured by the Vulcan Iron Works of Wilkes-barre, Pa. The track gauge was three feet. The cars were of the double dump type, costing about $300.00 each delivered. The locomotives cost $3,500.00 each delivered. The grades on the track were plus 3% for a loaded train, and minus 6% for an empty train returning to the steam shovel. These trains operated on the circuit, one filling, one in transit and the other dumping. When things were running smoothly, a train was loaded in four minutes, or at the rate of three shovel buckets per minute.

The shovel was of 2½ yards capacity, and two buckets were loaded to the car. Two eight-hour shifts were worked. The day shift usually put in 50 per cent. more material than the night shift. From four to five hundred cars were placed per day, the best day's run being 700 cars. The trains were diverted to the slopes of the dam alternately, and while the train was using the track on one side, the track on the other side could be shifted or raised. Fully half the men who were employed on the dam were engaged in this track shifting and tamping, and nearly half the cost per cubic yard of putting material in place was due to track work.

Water for Construction

The waters of Haiwee Creek were carried three miles and those of Hogback Creek were

SOUTH HAIWEE DAM, LOOKING EAST, SHOWING METHOD OF CONSTRUCTION

brought five miles in riveted steel pipe, and were discharged into the pool between the two toes of the dam. In this pool two steel hulls were floated, 20 feet long, 10 feet wide, and 2½ feet deep. On the first one that was built, a 6-inch Krogh centrifugal pump, directly connected with a 30 horse power motor, was mounted. The pump discharged the water from the pool through a 2-inch nozzle against the dump made by the trains. Energy was furnished the motor through an insulated cable carried on a reel on the hull. The reel permitted the shifting of the position of the pontoon. The jet discharged against the dump, washing the material down towards the pool, the finer particles proceeding towards the center of the pool and the coarser material staying on the outer edges.

It was originally the intention to build the dam by a hydraulic process, pumping the materials into the fill direct, but the water supply was found to be insufficient during the summer months to permit of this method of work, and the material available at proper elevations contained too many boulders.

The inner face of the dam was paved on the water side with rock riprap to a depth of two feet, to prevent erosion from wave action. After all the earthwork was placed, the track was taken up from the pits where the steam shovel had been working and laid to a rock cliff 1½ miles below the dam, where large quantities of basalt blocks were available. The track was laid on a 3 per cent. grade upon the outer face of the dam to the top and the dump cars loaded with riprap were discharged down the face of the dam to the point of use. No quarry work was required other than the loading of cars. It was found advisable later to lay concrete facing upon the riprap.

Gate and Outlet*

The top of the dam is 14 feet above the maximum water level. The gate tower is 14 feet inside diameter and 80 feet high. The gates are the ordinary sluice gate type, and are in pairs opposite each other. Each pair of gates will have a capacity sufficient to deliver 430 second feet of water under a head of 4.6 feet. It is the intention to use only the gates next to the water surface for the delivery of the water, in order to avoid operating them under high heads. The cost of this tower was $15,357.00.

*See Plate No. 15. Plan and Cross Section Haiwee Gate Tower—in map pocket.

The outlet from the reservoir is by means of a tunnel 1,200 feet long, excavated through shale. It is circular in section and 10 feet in diameter in the clear. It is lined with concrete and a steel pipe inserted for one hundred feet in the down-stream end. An arrangement was made for subsequently connecting this pipe with a riveted steel penstock for a power plant below. There is a drop of 196 feet from the maximum surface of the lake to the end of the proposed penstock, in a distance of 10,000 feet, which is available for the generation of power. When this power plant is established, it is the plan to have a working pressure available from the surface to the reservoir.

As the tunnel will be under 77 feet of maximum pressure head, it is desirable to have a tight bond between the concrete lining and its roof. Grouting accomplished this purpose.

There is a total of 598,747 cubic yards of earth in the South Haiwee Dam. The cost of the entire structure, including the core wall, was $268,095.38. The unit costs for this work are shown below. They include all direct charges to the work, but do not include auxiliary expenditures, such as administration, equipment, roads and trails, water supply, etc. These auxiliary expenditures amount to about 32½ per cent.

COST OF SOUTH HAIWEE DAM

	Total Cost	Quantity Cu. Yds.	Unit Costs
Preliminary work—test pits building railroad, etc.	$29,705.91	598,747	.0496
Core wall excavation	28,131.58	27,032	1.04
Core wall timbers	41,547.63	27,032	1.53
Core wall puddle fill	7,170.02	25,000	.29
Main fill	148,870.15	598,747	.248
Paving—riprap	11,268.14	16,110	.70
Engineering	1,401.95	598,747	.0023
TOTAL	268,095.38	598,747	

The cost of the concrete gate tower, containing 726 cubic yards of concrete, and gates, was

$15,357.25, the segregation of which is shown below. The tower was built of tufa cement. The same percentages as noted above applies for auxiliary expenditures:

Gates	$ 7,630.83
Tower (steel)	972.23
Concrete	6,236.06
Forms	380.78
Excavation	137.35
TOTAL	$15,357.25

Fairmont Dam and Reservoir*

The Aqueduct water is dropped 86 feet into the Fairmont reservoir, when empty, from the standard Antelope Valley conduit section, through an open ditch built of rubble concrete with side slopes of 1½ to 1. As the ditch extends into the reservoir the depth is decreased and the bottom width correspondingly increased. The erosive action of the water is minimized by having it enter the reservoir in a broad shallow sheet, rather than a deep confined channel. Further protection against undercutting and back-wash was obtained by building concrete aprons 10 feet wide on each side of the intake for its entire length. This apron has a slight reverse slope, so that its outer edge is in excavation, and a concrete cut-off wall is built along its outside edge. The end of the intake is protected by a deep cut-off wall and rubble pitching.

The Fairmont Dam is earthfill, with a concrete core wall. It will have a maximum height of 115 feet, a length on top of 1,516 feet and a crest width of 20 feet. The side slopes are 3 horizontal to 1 vertical on the water side, and 2 horizontal to 1 vertical on the other side. The volume of the fill will be 607,114 cubic yards. The crest elevation is 3,046 feet, and the maximum water surface will be 10 feet below the top of the dam. The core wall will be two feet thick on the top and four feet thick on the bottom and extends to within five feet of the crest of the dam. In addition to this dam there will be, in connection with this reservoir, 2,600 lineal feet of earthen dykes ranging in height from 5 to 20 feet and containing in all 116,749 cubic yards of material.

*See Plate No. 16. Plan and Topography of Fairmont Reservoir—in map pocket.
*See Plate No. 17. Cross Section of Fairmont Dam—in map pocket.

The storage in this reservoir is chiefly valuable for power purposes and is not essential to the delivery of 400 second feet at the end of the Aqueduct. It will be of value, however, as a safety factor in case of minor repairs that may be required on the 135 miles of conduit between it and the Haiwee reservoir, as it will, when full, deliver a full flow to the Aqueduct below for a period of nine days. This reservoir is the forebay to the large power plants as illustrated on the profile, and by means of it maximum discharges of 1,000 second feet may be delivered to meet the electrical peak in Los Angeles.

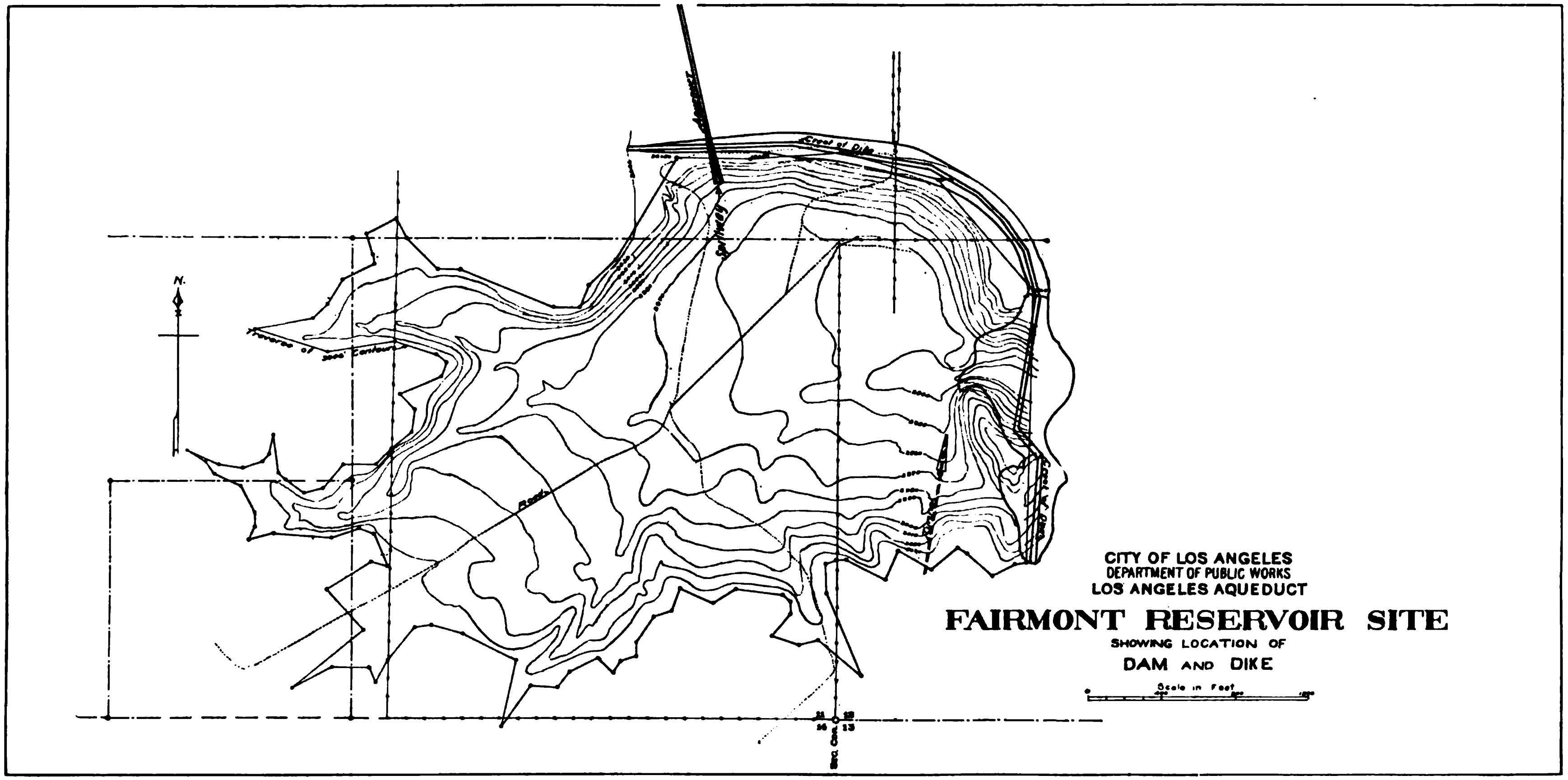
Concrete Core Wall

The dam was constructed first to an elevation of 2,970 feet, or 10 feet above the top of the Elizabeth Tunnel, which is adequate for diversion purposes. A trench was excavated into bed rock along the central axis of the dam, and the core wall was keyed into the rock abutments on the side. Bed rock was encountered at a depth of about 10 feet below the stream bed. The concrete core wall was built in this trench and raised to an elevation of about 2,970 feet. The outside of the fill on the lower toe of the dam was made of dump from the Elizabeth Tunnel. Approximately 190,000 cubic yards of material were placed in the dam. Of this, 107,000 cubic yards were earth fill, in greater part on the water side of the core wall. The material was loaded on wagons by a steam shovel in the bed of the reservoir and hauled to the dam and dumped on either side of the core wall. A pool of water was formed between the core wall and the upper toe, and a centrifugal pump, mounted on a float, jetted the water against the material on the toe, washing it down into the pool. The earth as it was dumped by the teams was spread by Fresno scrapers and men were kept wetting it down with hose. The water face of the completed portion was paved with riprap.

The total cost of the work done on the dam has been $60,190.00. In the core wall, 3,439 cubic yards of rubble concrete were placed at a cost of $9,000.00.

CORE WALL OF FAIRMONT DAM (Unfinished)

FAIRMONT RESERVOIR, LOOKING SOUTH FROM INTAKE



This Reservoir lies on the northern slope of the Coast Range and regulates the Aqueduct flow through the Elizabeth Tunnel

The earth materials available for the building of the dam are deficient in clay when used without thorough hydraulic segregation of the sand from the clay. There is a scarcity of water in the desert region and the hydraulic process of building was not possible for this reason. This is the reason for building the core wall. All the water available was used to wash the fine material in the upper portion of the dam against this wall, in order to make the center tight. Even with materials deficient in clay, a tight core wall can be obtained by the proper manipulation of the inflow into the basin that is carried up between the two toes of the dam. By placing the muck from the two and a half miles of excavation of the Elizabeth Tunnel in the lower toe, an economy was effected and drainage was provided at that point.

As the principal value of the Fairmont reservoir is for the generation of power, the arrangement is for the Power Bureau to provide the funds for its completion.

Gate Tower

The outlet from the reservoir is through a gate tower into the Elizabeth Tunnel. This gate tower is larger and much heavier than the one at Haiwee, as it must pass 2½ times the volume of water, although built upon the same general plan. It is 18 feet inside diameter. The walls are five feet thick at the bottom, three feet thick at the top and heavily reinforced, both vertically and horizontally, with steel rods. It is built on bed rock on a large concrete footing.

The gates in the tower are the cast iron sluice type, 4 feet 6 inches by 5 feet 6 inches. There are four tiers of three gates each, and a tier of gates is designed to discharge 1,000 second feet of water. The feature of this arrangement of the gates is that they will operate under low heads, the water always being drawn through the pair that are but slightly submerged. Heavy grillage is placed in the tower at various levels to break the force of the falling jet, and the floor of the tower is heavily reinforced with rails imbedded in the concrete.

The point where the tower connects with the North Portal of the Elizabeth Tunnel will be under a pressure head of 80 feet. This connection is circular and heavily reinforced with steel. The lining of the Elizabeth tunnel was strengthened for a distance of about 400 feet in from the portal, or to such a distance that would take the tunnel beyond the high water line of the reservoir. This strengthening consisted of an inner shell of concrete, eight inches thick, reinforced with 16-pound rail spaced 18 inches center to center.

Dry Canyon Dam and Reservoir*

This reservoir is located at the end of the 1,000 second-foot tunnels below the main power sites, and is used to regulate the fluctuating flow through the power plants back to the normal delivery. Its position is shown in the profile. The water enters the reservoir from the South Portal of Tunnel No. 77 through a rubble-lined open conduit. The slope of the ground surface is very slight at this point, and the canal is extended into the reservoir until their grades intersect. The side walls of the intake canal are sloped 1 to 1 and are paved with rubble up to the original ground surface.

The Dry Canyon Dam is earth fill, with a clay core cut-off wall, extending to bed rock. The dam has a center height of 61 feet, a crest width of 20 feet and a length of 528 feet. The side slopes are 2½ horizontal to 1 vertical on both sides. The volume of the fill in the dam is 140,000 cubic yards. The cut-off trench is 6 feet wide and 70 feet deep across the bottom of the canyon, and 5,350 cubic yards of material were excavated from this trench.

The elevation of the crest of the dam is 1,511 feet and the elevation of the maximum high water 1,505.236 feet. The elevation of the hydraulic grade at the outlet is 1,500.34 feet. The normal fluctuation of water levels in this reservoir is about five feet. The water side of the dam is paved with concrete sufficiently to guard against wave erosion below the normal low water. The top and outside face of the dam are protected with an oil dressing.

*See Plate No. 18. Cross Section Dry Canyon Dam—in map pocket.

*See Plate No. 19. Plan of Dry Canyon Dam—in map pocket.

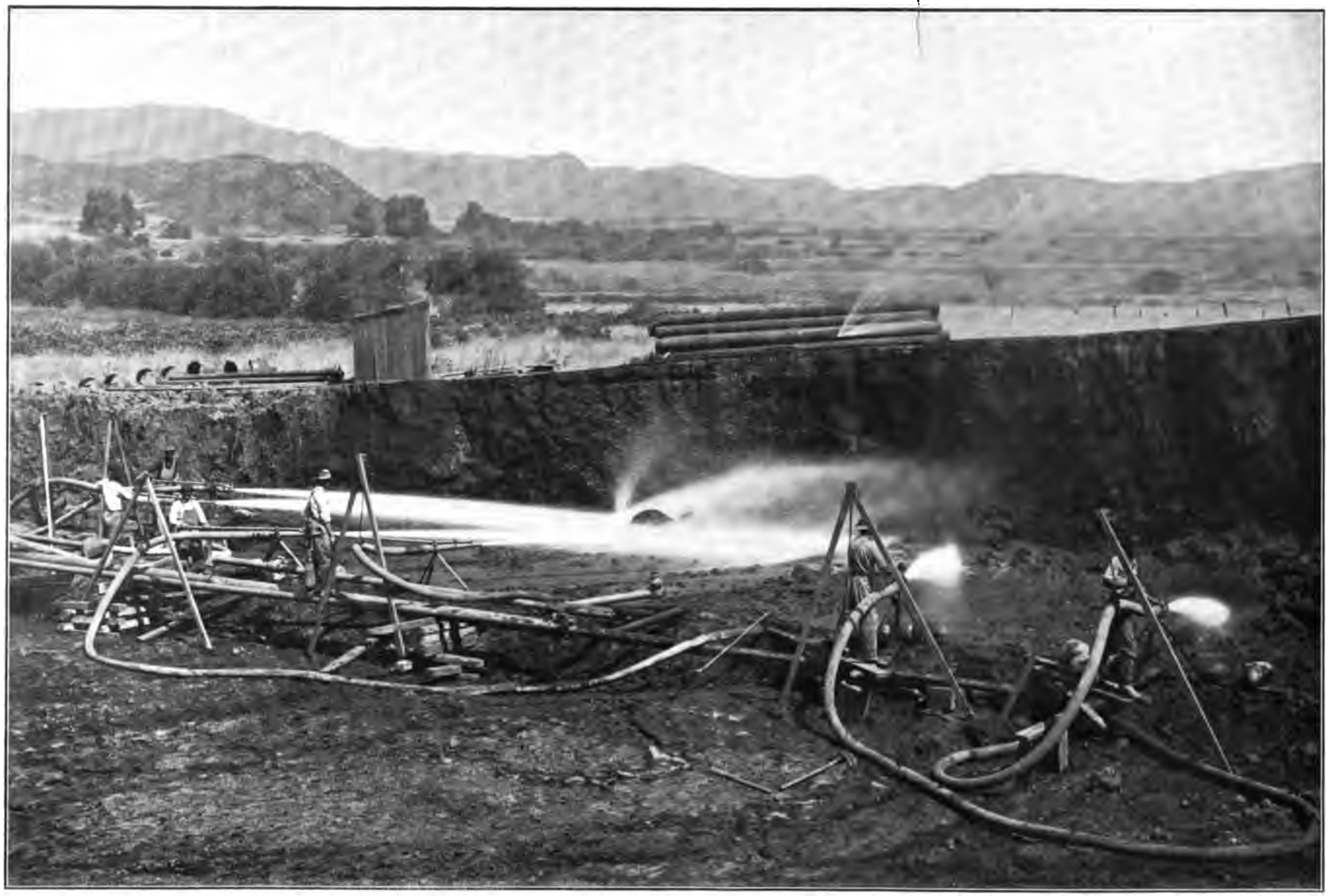
UPSTREAM FACE OF CANYON DAM

DRY CANYON RESERVOIR, SHOWING FLOATING WEIR

Dry Canyon Dam, Looking East, Showing Finished Structure. The Wasteway of the Reservoir is visible in the Background

DRY CANYON RESERVOIR PARTLY FILLED

EARLY STAGE ON CONSTRUCTION OF SAN FERNANDO DAM



HYDRAULIC WORK ON SAN FERNANDO DAM

VIEW OF SAN FERNANDO RESERVOIR FROM DAM

OUTLET TUNNEL OF LOWER SAN FERNANDO RESERVOIR

Cut-off Trench

Test pits at the dam site indicated a soft shale bed rock at a depth of about 75 feet, overtopped with water-bearing gravel. The excavation of the cut-off trench was an interesting and difficult piece of work. A shaft was sunk in the rock on the east abutment to the level of the lowest bed rock in the center of the canyon. A drift was run from the bottom of this shaft along the axis of the dam in the bed rock to the water bearing gravel. At the end of the drift and along its roof, perforated 2-inch pipes were driven diagonally up into the water bearing area and the water drained to the bottom of the shaft, and pumped out with a 5-inch centrifugal pump. The trench was then excavated from the surface and extended down as the water plane receded. The material was shoveled into buckets and hoisted with small stiff-leg derricks, operated with electric motors. After the excavation, the trench was again allowed to fill with water. A steam shovel outfit was installed near the dam, and wagons were loaded with clay by it and dumped alongside the trench. This material was then pushed into it with a road surfacing machine. The core wall was compressed in water under its own weight and the weight of the superimposed dam. The drift under the dam was refilled from the bottom of the trench and from the shaft.

The toes of the dam were built up by teams loaded by the steam shovel and compacted by hauling back and forth over them. Water was diverted from the San Francisquito Creek to the dam site and a small pond formed against the upper toe of the dam. A pumping plant was established here and the water conveyed in pipes and jetted against a clay bank about 500 feet from the dam site. The jets knocked down and dissolved the clay bank, and the muddy water was collected in an open earthen channel and run to a sump near the upstream toe of the dam. Here it was picked up by a "mud pump" and carried in pipes to the basin between the two toes of the dam. The discharge pipes were so arranged that the muddy water was delivered at the extreme outer edges of this pool on both sides of the dam, the finer and impervious materials being conveyed to the central axis of the dam connecting with the core wall in the trench. Deep samples taken from the center of the dam after its completion were very dense.

Regulating Gate*

The water levels in this reservoir will fluctuate normally about five feet. The outlet from the reservoir is into the standard 400 second-foot tunnel section. A regulating gate or module had to be provided which would deliver to this tunnel a constant flow of 400 second feet with a fluctuating water surface in the reservoir. This regulating gate is a floating weir consisting of an annular sheet iron tank, 30 feet inside diameter, 4 feet thick, and 12 feet high, fitting around a circular concrete wall. The tank will float, sliding up and down over the concrete wall, as the water surface in the reservoir raises and lowers, much as a gas tank acts. Guide bearings are provided on columns to prevent the tank from binding. Stop-cocks are placed in it, so that water may be admitted and the whole tank sunk to such a depth that the flow over the weirs is 400 second feet. If the float sinks too low, it may be raised by pumping out part of the water. Then whatever the elevation of the water surface in the reservoir may be, the tank will float at a constant depth below it, and the discharge over the top will remain constant. The water flowing over the tank falls into the basin inside the concrete wall. A short inverted siphon leads from the bottom of the basin into an open forebay at the portal of the tunnel. The water flows through this siphon into the forebay and out through the tunnel. Emergency gates, of the ordinary cast iron sliding type, are provided in the walls of the forebay, so that water may be admitted to the tunnel if anything happens to the floating gate.

A blow-off pipe is provided under the dam, so that the reservoir may be emptied if necessary. This is a 24-inch cast iron pipe encased in concrete, with large concrete wing walls built at intervals along it to cut off any seepage along the sides. This pipe was built in

*See Plate No. 20. Plan of Dry Canyon Automatic Regulating Gate—in map pocket.

place before any fill was put in the dam. It is operated by a 24-inch gate valve on the outside of the dam. The intake to the drain pipe is protected from being choked up by an iron grating mounted on tracks in a steel frame tower. This tower is built to an elevation above high water in the reservoir and permits the grating to be raised and cleaned while the reservoir is full.

Work was started on this dam in December, 1910, and it was completed in February, 1912. On March 9th, 1911, a flood occurred, which washed out 3,600 cubic yards of dry fill and 1,100 cubic yards of hydraulic fill. This material, however, was replaced by the end of that month. The financial loss by this flood was $1,941.00.

The unit and total costs for work on this dam are given below. They include only the direct field charges to the work:

COST OF DRY CANYON DAM

	Quantity	Total Cost	Unit Cost
Corewall Trench—			
Exc. and Timbering	5,350 cu. yds.	$21,710.32	$4.06
Puddle Fill	5,350 cu. yds.	3,902.62	0.73
Hydraulic Fill	45,610 cu. yds.	8,038.36	0.176
Dry Fill	95,390 cu. yds.	25,207.55	0.26
Eng. & Supervision	141,000 cu. yds.	2,490.79	
Spillway—Concrete	146 cu. yds.	860.72	5.98
Outlet Gates—			
Concrete	293 cu. yds.	2,014.31	6.86
Surfacing—Concrete	470 cu. yds.	1,385.47	2.95
Drain Pipe—complete		5,290.89	
Spillway Excavation		854.02	
Surfacing—Oil		1,224.35	
Outlet Gates—			
Excavation, Machinery, etc.		3,377.35	
Loss by Flood		1,941.27	
Miscellaneous Expenditures		2,374.82	
Total cost dam complete		$80,672.84	

Cost of surfacing concrete..................62 cts. per sq. yd.
Cost of surfacing oil.............................. 9 cts. per sq. yd.

The materials for the building of this dam were satisfactory except that they were expensive to obtain. That excavated by the shovel was a soft shale, which packed down hard in the dam when wet down and rolled by the traveling teams. The haul was about 700 feet to the dam. Bottom dump wagons holding two cubic yards were used, and three animals were hitched to a wagon. The material that was hydrauliced was a four-foot stripping off the top of the shale. The water supply for this work was usually deficient, though the pond between the two toes of the dam was drained back and repeatedly used, and these two factors made a unit cost that otherwise would have been materially less. The method of draining the gravels for the sinking of the trench was entirely successful, but more expensive than that used at Haiwee, where the pumps were operated directly in the trench.

Hydraulic Process

The conditions for building hydraulic dams were not ideal on the Aqueduct. Quantities of water of from 10 to 15 second feet, delivered under gravity pressure of 100 pounds or more at the nozzle, to the earthen banks, which are at sufficient elevation to run the muddy water to the dam on from 4 to 6 per cent. grade, are all desirable features on this class of work. In their absence, centrifugal pumps had to be resorted to, and the use of the water over and over by return draining was necessary. Two and three stage centrifugal pumps were used for the jets, the pressure for the nozzles being held at from 80 to 100 pounds per square inch and the size of the pump selected to fit the amount of water available, which was usually from 4 to 8 second feet. The percentage of material that may be transported by the water varies greatly with the character of the earthen bank and is difficult of exact determination. A sample settled in a glass graduate for a few hours may show 15 to 20 per cent. of loose silt, which when dried and weighed will indicate 4 or 5 per cent. of the weight of the water. Ordinary fire nozzles with 2-inch openings, connected with the steel pipe mains with a short piece of 4-inch canvas hose, were used. The nozzles were mounted on iron tripods with swivels. Well casing with Dresser connections was used for force mains.

The "mud pump" was also of the centrifugal type, but of a single stage and designed by the maker to pass gravel and small stones without injury. When material containing

large quantities of sand was pumped, the sides and runners were badly cut, and it is desirable to use a pump that will permit of these parts being replaced. The lifts from the sumps vary as the crest of the dam rises. The reason for building these dams by various hydraulic processes was that it gave the desired arrangement of the fine clay material in the center of the dam and the sand and gravel near the outer slopes, resulting in an impervious core with outside drainage, and a compacting of the mass by settlement. The Silver Lake dam, which is of this class, was built by the Los Angeles City Water Department, and has proved satisfactory. It has a depth of water against its face of 50 feet.

The cost of handling earth with water is cheaper than loading wagons with power shovels and transporting to the dam, even with the necessary pumping and small volumes of water, as is shown by the cost data given for the small North Haiwee and Dry Canyon dams. At the large San Fernando dam, which is under construction by the Water Department and which will contain 2,700,000 cubic yards of earth, larger equipment and greater quantities of water are used, but the same general pumping arrangement is applied and the costs are substantially lower.

This method of work is a western development and when properly built, these dams are a success. Where failures have occurred elsewhere, it has been due to discharging the silt into the central portions of the dam, or to undue rushing of the work which may cause slips in the outer faces.

Materials deficient in clay and containing less than 35 per cent. of this necessary fine material, which could not properly be used except in connection with concrete core walls, may be safely accepted for hydraulic dams, provided proper methods of delivery are used, for the clay may be concentrated into the central core by the segregation effected by the water, and the outer slopes composed of the coarser material favor both stability and drainage.

TUNNEL CONSTRUCTION

The tunnel construction on the Los Angeles Aqueduct proved the most satisfactory class of work accomplished because of the directness of the line, its freedom from attack by the elements and the safety against breaks in the conduit. The whole tendency during the construction of the work was to increase the number of tunnels. When the Board of Consulting Engineers first passed on the line, 28 miles of tunnels were shown on the location, while the line as finished contains 42.9 miles of tunnels on the Aqueduct proper and 8.8 miles of power tunnels, or a total of 51.7 miles. The tunnels were generally driven cheaper than the original estimates in all classes of formation.

Tunnel Equipment

Practically all of the rock tunnels were driven with machine drills. Central air compressor stations were built. There were on the work 14 Rand cross compound compressors of 500 cubic feet per minute capacity, which delivered air at 100 pounds pressure per square inch. There was no difficulty in piping air as much as 3 miles in 3½ or 4-inch pipes. The compressors were belt driven with electric motors, operated with electric power from the hydro-electric plants. The work was mostly equipped with Leyner air hammer drills. These drills are the most satisfactory in principle, in that the blow is struck with an oscillating hammer and the drill is not moved in and out to strike the blow. The device for delivering a jet of water through the drill stem to the point of the bit, thus keeping the hole washed clean at the point of the drill is a good one. The defect of this drill, as used on the Los Angeles Aqueduct, consisted in the poor material used in its construction and consequently in the large repair bills that were involved. This defect not only involved the cost of making replacements, but also caused a more serious loss due to the interruption of the work. This objection was largely eliminated in the drills that were later purchased.

In Tunnel No. 7 on the Little Lake division, which was in rather soft granite, the cost of drill repairs amounted to 28 cents per lineal foot.

Drilling and Firing

In the hard rock tunnels, the depth of the holes was so adjusted that each shift would drill, load and fire a full round of holes during the eight-hour shift. The new shift coming on would then clean up the muck from the previous firing, and put in and fire a new set of holes. This usually meant that the holes were driven 5 or 6 feet in depth. Two drills were usually run at the same time from a tunnel bar. Four-foot holes, placed approximately in the form of a square, about 4 feet on a side, were driven almost to a common center at their bottom. They are called the "Cut-holes." A group of holes was then placed around the side and top near the outside of the tunnel (called the "back holes") and 4 "lifters" driven last, at equal intervals, at sub-grade in the bottom of the tunnel. Additional holes were driven as the size of the section and character of the rock required. All of the holes were then loaded and the fuse cut in such a manner that the "cut" holes would go first, blowing out the wedge from the center of the excavation, followed by the explosion of the top and side holes, which would break the material down to the center cut, and the last holes to go would be the bottom ones, called the "lifters," which would break to the bottom and throw the muck pile back from the face.

An effort was made to use electric exploders, but these were not found satisfactory. Ordinary exploders could not be used, because the holes had to go off in the order indicated and could not be shot simultaneously. The experience on the Los Angeles Aqueduct coincides with that of other tunnel engineers to the effect

PORTAL OF ELIZABETH TUNNEL, WHERE AMERICAN HARD-ROCK RECORD WAS MADE

that a powerful, high-grade cap should be used in order to get the complete detonating or explosive force of the powder. Substantially greater explosive effect from the powder was obtained with the 15-grain fulminate of mercury cap than with the 10-grain cap. High-grade imported German fuse was used throughout the job, and it is believed that this not only was economical, but was responsible for the almost complete absence of mis-fires and slow fires. Five million pounds of powder were used in building the Aqueduct, and only 5 fatalities occurred from explosions. This satisfactory record is believed to be largely due to the high grade fuse that was used.

Explosives

The powders used in tunnel driving were 40 and 60 per cent. gelatine and 40 and 60 per cent. ammonia powders. Both of these give off the minimum quantities of noxious gases from explosion. It was possible to go into the tunnels after firing a round of holes almost immediately without injurious effect. It was noted that very little difference in explosive effect was obtained between the 40 and 60 per cent. ammonia powders, but that substantial difference was obtained between the 40 and 60 per cent. gelatine powders. The straight dynamites could not properly be used in tunnel work, because of their noxious gases, but were better on outside work.

In driving tunnels, the problem to work out in order to achieve speed is getting rid of the muck. A mucking machine was tried, but found entirely unsatisfactory, and the tunnels were too small to use any type of power shovel. Rapid mucking was accomplished by the installation of the bonus system, and the records that were made in tunnel driving were largely due to this method of extra pay.

Excess Yardage

Too much care cannot be exercised to avoid overshooting in tunnels, because of the excess yardage that is involved when it comes to lining them with concrete. Some tunnels were driven and trimmed so closely that this excess yardage of concrete did not exceed 15 or 20 per cent. of the theoretical yardage of concrete, but the cost of this trimming amounted to as much as $2.00 per lineal foot of tunnel, and probably too much time and care were put upon it. As a rule the excess yardage of concrete was from 40 to 50 per cent. of the theoretical, and in some tunnels as much as 100 per cent. Experience indicates that rock tunnels should be driven so that the excess yardage of concrete lining may not be over 30 or 40 per cent. In driving tunnels, frequent measurements should be made of their cross-section to determine what this excess is. Where a yard of concrete to the lineal foot of tunnel is being placed, 100 per cent. excess could readily amount to $6.00 or $7.C0 per foot, and a 30 per cent. excess would represent $1.80 per foot. Tunnels in ordinary rock should be driven with a small amount of trimming; as close as this percentage. It has been found to be the best practice to so excavate the sub-grade at the start that the top of the ties is on the bottom of the theoretical sub-grade, so as to avoid expensive trimming and delays when it comes to concrete lining.

Tunnel Tracks

Good tracks are desirable in long tunnels. No rails should be used weighing less than 25 pounds to the yard. A good track is important for the rapid transportation of the muck, especially if electric locomotives are used, and it is still more important in long tunnels, when it comes to the concrete lining, where it is important to transport wet concrete with high speed. The concrete cars are unavoidably top heavy and a concrete car off the track is a serious thing, as it not only delays the work, but may result in the setting of a train load of material.

The electric locomotives used for tunnel work were highly satisfactory and efficient machines, manufactured by the Westinghouse and General Electric companies. Up to lengths of haul of ½ mile, there was not much saving due to the electric locomotive, because of the equipment involved and the cost of operation, not only of the motor, but of the power house.

TUNNELS GRAPEVINE DIVISION

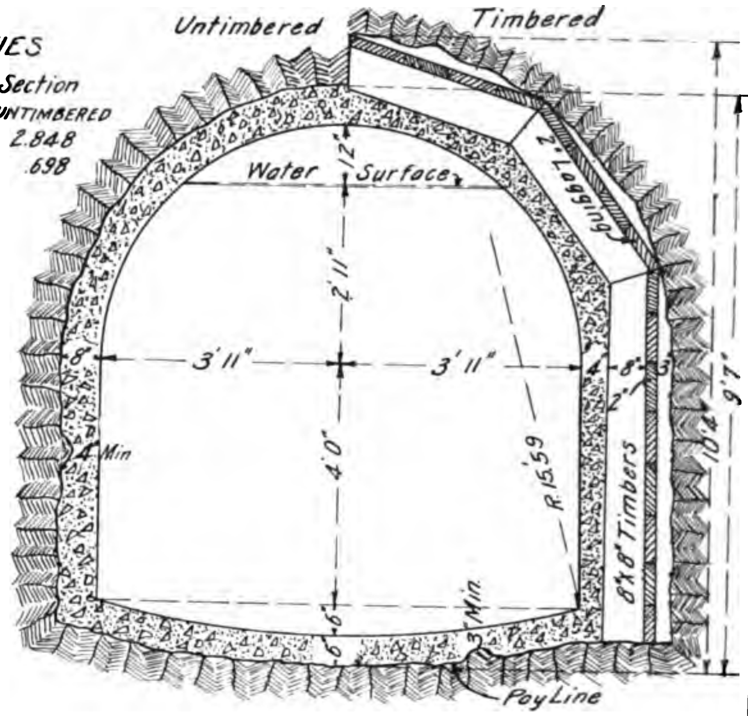
CONSTRUCTION QUANTITIES

Per lineal foot of Tunnel Normal Section

	UNIT	TIMBERED	UNTIMBERED
Excavation	Cu. Yd.	3.514	2.848
Concrete in Lining	" "	.945	.698
Timbers	B.M.	32.0	
Spreaders	" "	5.0	
Shoulder Braces	" "	7.0	
Lagging	" "	47.0	

HYDRAULIC PROPERTIES

S =	.0017
Q =	434.13
V =	7.97
A =	54.462
P =	22.499
R =	2.42
n =	.014
C =	124.29



TUNNELS ANTELOPE DIVISION

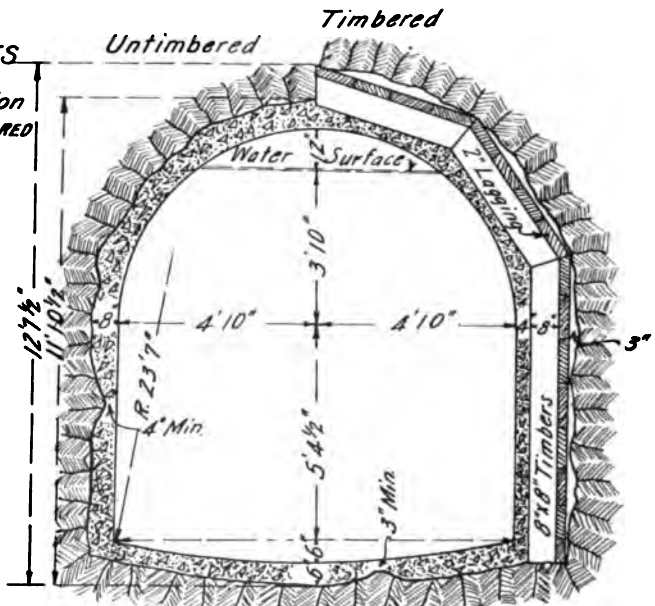
CONSTRUCTION QUANTITIES

Per lineal foot of Tunnel Normal Section

	UNIT	TIMBERED	UNTIMBERED
Excavation	Cu. Yd.	5.12	4.22
Concrete in Lining	" "	1.13	0.81
Timbers	B.M.	4.25	
Spreaders	" "	5.0	
Shoulder Braces	" "	7.0	
Lagging	" "	60.0	

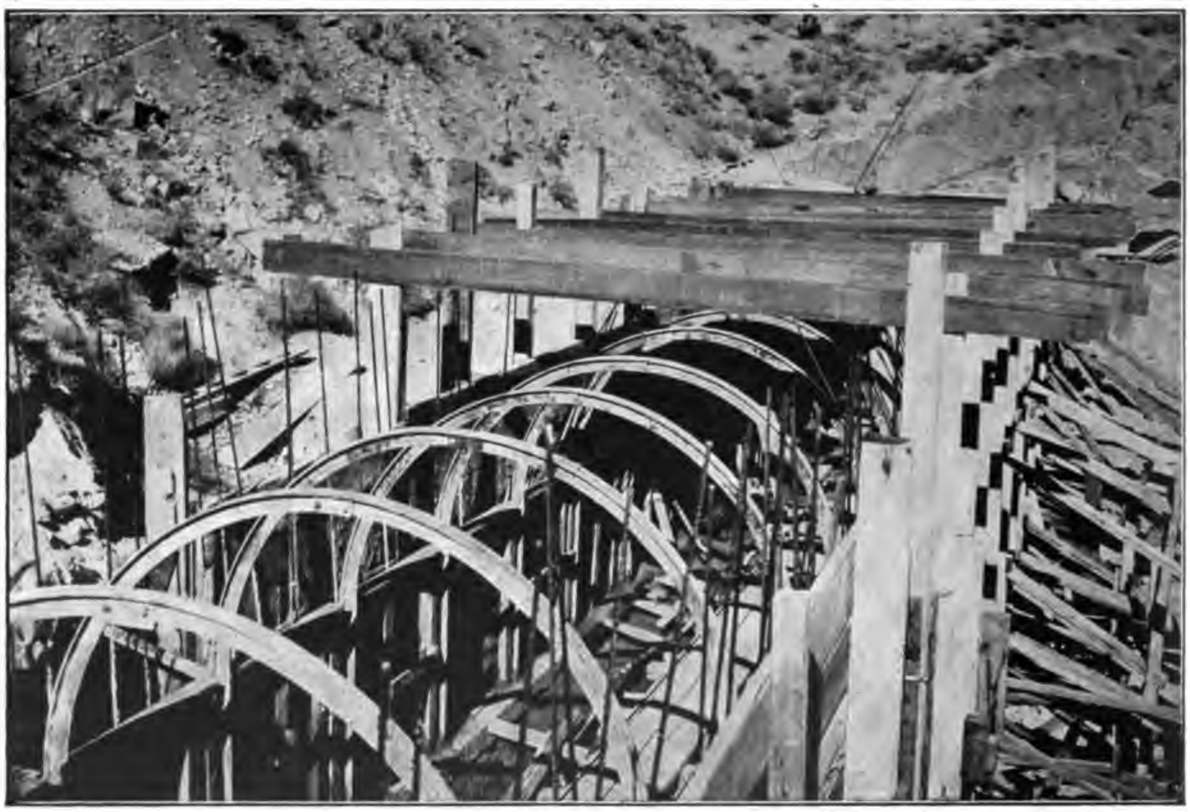
HYDRAULIC PROPERTIES

S =	.0005
Q =	434
V =	4.94
A =	87.95
P =	29.31
R =	3.00
n =	.014
C =	127.4



Standard Types of Tunnels in the Grapevine and Antelope Valley Divisions

A Lined Tunnel in the Saugus Division



Short Section of Aqueduct Between Tunnels Where Tunnel Forms Were Used

One of the essential features in rapid tunnel driving is efficient ventilation. Root positive blowers were used almost universally on this work. It was possible to ventilate the Elizabeth tunnel so that men could return to work within 20 minutes after the firing of a round, when the heading was being driven two miles in from the portal, and the 18-inch blower was set up outside of the tunnel.

A good system of electric lighting facilitates the work and decreases the danger in the tunnel.

In short, for the economic driving of hard rock tunnels, it is the best economy to get high-grade equipment of excess capacity to start with. No amount of energy or skill can overcome deficient equipment.

The Bonus System for Tunnels

It was recognized at the beginning of the work that the outside conduits and the pressure pipes could be built as rapidly as desired, within reasonable limits, depending upon the organization of the work and the way in which funds were made available for carrying it on. Enough equipment was purchased to build this portion of the work within the five years specified by the Board of Consulting Engineers for the completion of the project. The controlling factor in point of time was regarded by all to be the great length of tunnels, 164 in number, and especially the Elizabeth tunnel, which is more than 5 miles long, and which had to be driven from two headings only. This tunnel, which is 20 miles from a railroad base of supplies, passes through the crest of the Coast Range, and requires lining throughout with concrete. A fair rate of progress for tunnels of this size, and in a geological formation such as here encountered, is a mile a year from the two headings, or five years for the entire 26,870 feet.

It was manifestly important, therefore, to devise some method of work which would develop speed, especially in the Elizabeth tunnel, as it was essential to promptly deliver the water to the City, and to avoid undue interest charges on the bond issue. The bonus scheme was adopted. This was modified from time to time, as experience was gained in its application, and the schedule herewith presented is the final outcome.

Theory of the Bonus System

The tunnels were driven for a few months, and the number of men who could work efficiently in the headings, together with their progress, was noted under different conditions. A standard size crew was then authorized, which could not be exceeded. In the Elizabeth tunnel, the number was 16 men for untimbered tunnel and 23 for timbered tunnel. Only those engaged inside on the driving of the heading, trimming, timbering, etc., were included in the bonus crew. The required progress was fixed. At the Elizabeth tunnel it was 8 feet per day, or 2⅔ feet per shift for untimbered tunnel, requiring the excavation of 4.18 cubic yards per lineal foot, and 6 feet per day, or 2 feet per shift for timbered section of the tunnel, requiring the excavation of 5.02 cubic yards per lineal foot, and the placing of 115 feet board measure of lumber. A base wage was paid of $3.00 per day for miners and timbermen, and $2.50 per day for muckers (shovelers). In wet tunnels, 50 cents a day additional was paid. Eight-hour shifts were worked.

For all excess footage over the base rate made by a shift each man on the shift was paid 40 cents a foot in the Elizabeth tunnel. In other tunnels the bonus paid varied from 20 cents to 40 cents per foot, depending on the character of the rock. Each tunnel was inspected by the Chief Engineer or his assistant, and a reasonable rate of progress and bonus pay determined, which when approved by the Board of Public Works, was effective for that tunnel. The superintendent and foremen did not share in the bonus pay, as it was their duty to see that the quality and quantity of the work was up to par. Measurements were made on the 10th, 20th and last day of each month to determine the progress. Any man receiving bonus was required to work continuously through the ten-day bonus period.

The theory of the schedule is to pay the men a fair wage for the day's work, and in addition to give them a share approximating 50 per

ELIZABETH TUNNEL

Pressure Tunnel

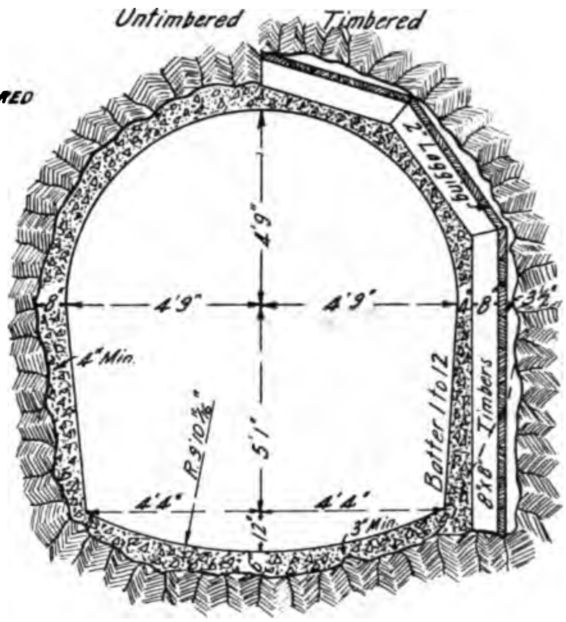
CONSTRUCTION QUANTITIES

Per lineal foot of Tunnel Normal Section

	UNIT	TIMBERED	UNTIMBERED
Excavation	Cu. Yd.	4.90	4.05
Concrete in Lining	" "	1.185	.805
Timbers	B.M.	43.0	
Spreaders	" "	5.0	
Shoulder Braces	" "	7.0	
Lagging	" "	60.0	

HYDRAULIC PROPERTIES

S =	.001
Q =	1000
V =	11.426
A =	87.523
P =	34.09
R =	2.5675
n =	.014
C =	124.5



TUNNELS SAUGUS DIVISION

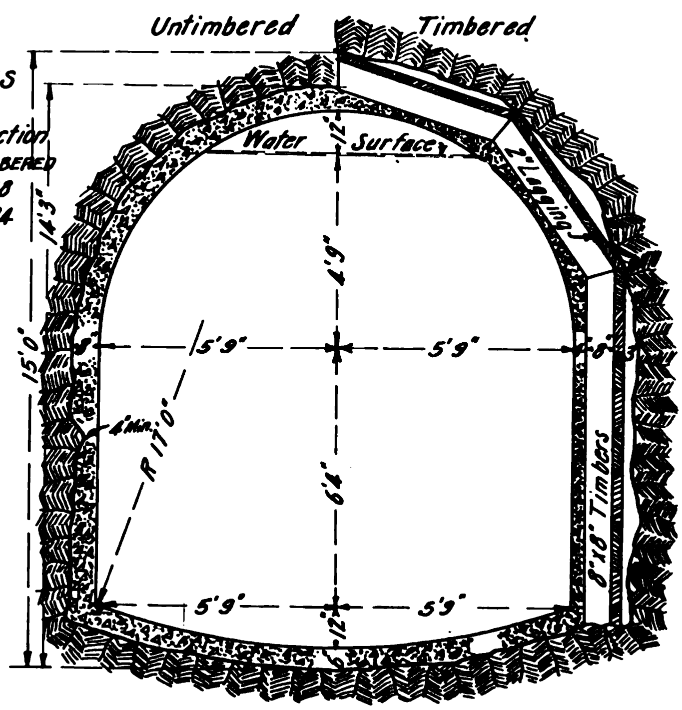
CONSTRUCTION QUANTITIES

Per lineal foot of Tunnel Normal Section

	UNIT	TIMBERED	UNTIMBERED
Excavation	Cu. Yd	5.02	4.18
Concrete in Lining	" "	1.105	0.84
Timbers	B.M.	43.0	
Spreaders	" "	5.0	
Shoulder Braces	" "	7.0	
Lagging	" "	60.0	

HYDRAULIC PROPERTIES

S =	.001
Q =	1000
V =	7.81
A =	127.87
P =	35.60
R =	3.59
n =	.014
C =	130.3



TUNNEL SECTIONS SOUTH OF FAIRMONT RESERVOIR

cent. of the estimated saving, in case the base rate of progress is exceeded. It must be kept in mind that the labor charge per day for the driving of a tunnel is a fixed amount, including not only those engaged in the tunnel, but also the outside organization of mechanics, superintendent and clerks. The cost of explosives and power varies with the footage made. Therefore, the greater the rate of progress, the lower the final unit cost of the work will be.

Effect of the Bonus

The sharing of the benefits with the men by means of the bonus system resulted in an improved relation with them. They became interested in the success of the work. The men in a bonus crew themselves eliminated the drones and did not tolerate loafing. The duties of the foremen and superintendent were almost entirely confined to getting the necessary supplies and equipment. As the bonus profits materialized, the miners not only remained longer on the work, but sent for other workmen whom they knew and who would do their share in increasing the speed.

In fixing the bonus and the base rate, it is important to reach a reasonable balance, which will allow the men a fair share in the saving, giving them a chance to earn from $10.00 to $30.00 a month as a reward for unusual effort. In some places where the bonus has been tried by other organizations, the base rate was placed so high that there was little opportunity for the men to profit by it, resulting in discouragement to them and no benefit to the organization.

In November, 1909, the tunnel work on the Los Angeles Aqueduct was in full swing. This particular month is selected for consideration only because the bonus pay rolls were so large that the City Auditor asked for an investigation of the bonus system to justify its use. A detailed study was made of it, which satisfied the Board of Public Works that it was decidedly beneficial. During this month, 9,131 feet of tunnels were excavated, of which 4,033 feet was excess footage over the base rate as fixed, which is an increase in speed of 72 per cent. Ninety per cent. of the crews earned bonus ranging from 12 cents to $1.95 per day for each man. In the 39 tunnel headings, the total wages for that month were $76,837.38, of which $13,133.94 was bonus, or 17 per cent. The average cost per foot of tunnel for labor and bonus was $9.87. If only the base progress, which was the estimated ordinary progress, had been made, the cost per foot for labor would have been $13.80. The footage gained over the estimated base rate cost in bonus pay an average of $3.25 per foot for all tunnels.

In the Elizabeth tunnel, the base progress of 420 feet for the two headings for the month was exceeded 429 feet. In this tunnel, where speed was particularly desired, the muckers, who had the hardest work to do and who largely controlled the rate of advance, worked in relays. A car holding 33 cubic feet would be pushed up to the pile of debris thrown down by the explosion and four of these shovelers would fill it. They would then push it back to the switch, and four fresh men shoved up an empty car and filled it,—the first crew meantime doing light work or resting. This process was kept up, so that a fresh crew would come up with each empty car. The result was that the American records for rapid hard rock tunnel work were repeatedly broken, and the world's record for soft rock tunnel driving, (so far as known) was beaten at Tunnel 17 M, in the Jawbone Division, where 1,061 feet were driven at one heading by hand work in August, 1909. The material in Tunnel 17 M was a soft sandstone which could be bored with augers.

The entire 26,870 feet of the Elizabeth tunnel was completed on February 28, 1911. The four years and seven months time set for the driving of this tunnel was beaten by 450 days, or 32 per cent. The average progress was 10.8 feet per day for each heading. This includes the time during which the tunnel was driven by hand, while the equipment was being purchased and installed. The rock is granite, favorable for rapid work at the south end, but uneven, full of water, difficult and dangerous at the north end.

The average cost per foot of the Elizabeth tunnel was:

Excavation, including timbering	$41.35
Lining	9.65
Local administration and superintendence	2.10
Equipment	7.92
Buildings, water supply, etc.	5.83
Engineering and surveys	1.00
Total	$67.85

This does not include general administration costs, which amounted to 3.55 per cent or $2.35 per foot, making a total cost of $70.20 per foot. The estimate of the Board of Consulting Engineers was $75.33 per foot plus 16.5 per cent for contingencies and water supply, making a total of $87.93 per foot. The saving therefore amounted to approximately $18.00 per foot or about $500,000 for the entire tunnel.

On the Jawbone division, bids were asked for all the construction of this part of the work, excluding siphons, but including 65,000 feet of tunnel. They ranged from $2,294,000 to $4,258,000. After a consideration of the bids received, it was decided that the work would probably cost the City less if it were done by day labor under the Engineering Department. This was done,—the bonus system was used in all of the tunnels and the actual field cost of all the work was $700,000.00 less than the lowest price bid.

Rules Governing Payment for Bonus Footage

1. Ten days shall constitute a period. The first period to be from the 1st to the 10th of the month, inclusive; the second from the 11th to the 20th inclusive; the third from the 21st to the end of the month. Bonus payments shall be allowed upon the basis of measurements made at the close of each ten-day period.

2. The following named classes of employes shall be allowed to participate in bonus payments:

Tunnel Foremen,
Shift Bosses,
Miners,
Muckers.

3. The tunnel foreman shall not be considered as one of the crew except when in charge of a single shift, when he shall share in the bonus on the same basis as the men of the crew under his direction. If he is in charge of more than one shift, he shall be allowed bonus based upon the average bonus progress of all headings under his supervision.

4. The shift boss shall be considered as one of the shift crew. He will participate in the bonus on the same basis as the men of the crew under his direction. An exception to this rule is made when a shift boss is placed in charge of two or more shifts in different headings. In this case, he would be placed on the same basis as a foreman—to-wit: not be considered as one of the crew, and would be allowed bonus upon the mean bonus progress.

5. The number of shifts worked in a heading during a day of 24 hours shall be determined by the engineer or superintendent in charge of the work after consultation with the Chief Engineer.

6. All back trimming must be done by the crew sharing the bonus. If the timbers are placed by the miners from the standard crew in a given ten-day period, then that portion of the tunnel shall be considered as a timbered section; otherwise it shall not be so considered.

7. Only men who work continuously through the ten-day period, with the following exceptions, shall be entitled to bonus:

(a) Any employe, entitled to bonus earnings, who is injured or becomes ill during a period from conditions arising directly from tunnel construction, shall participate in bonus in proportion to the number of shifts worked by him during said period.

(b) If an employe, entitled to bonus earnings, is transferred during a period from a heading to another part of the work for reasons other than his own request, he shall participate in bonus in proportion to the number of shifts worked by him on such heading.

8. If the work is interrupted by the failure of power, shortage of material or supplies, floods, cave-ins, or other causes beyond the control of the men, the men shall be entitled to bonus pay in proportion to the number of

ELECTRIC TUNNEL TRAIN, SHOWING ROCKER DUMP MUCK CARS

shifts worked by them during period in which such interruptions occurred.

9. To establish a uniform system of computing bonus earnings in above case, the following formula will be used:

$$\frac{x + y}{\frac{x}{a} + \frac{y}{b}} = \text{Average base rate per shift.}$$

Let x = Timbered progress = 25 ft.
y = Untimbered progress = 30 ft.
a = Required timbered per shift = 2 ft.
b = Required untimbered per shift = 2.5 ft.
s = Number of shifts during period = 20

Then

$$\frac{x}{a} = \text{shifts required at base rate.}$$

$$\frac{y}{b} = \text{shifts required at base rate.}$$

Or substituting values,

$$\frac{25}{2} = 12.5 \text{ shifts required at base rate.}$$

$$\frac{30}{2.5} = 12.0 \text{ shifts required at base rate.}$$

Total 24.5 shifts required at base rate.

$$\frac{25+30}{24.5} = 2.245 \text{ average base rate.}$$

20 x 2.245 = 44.9 = progress required.
55 — 44.9 = 10.1 ft. = bonus footage.

10. The computation of bonus footage shall be made by dividing the total number of feet run during the period by the total number of shifts worked during the period. From this average footage per shift there shall be deducted the base rate of progress required, and the remainder, if any, will be the bonus footage per shift. The bonus earned per man during the period will be the number of shifts in which he worked, times the average bonus footage, times the bonus price per foot. (Provided all conditions as outlined in these rules are complied with.)

Example 1.—3 shifts working 10 days

Total progress for period—150 feet.
3 shifts x 10 days = 30 shifts worked.
150 ft. ÷ 30 shifts = 5 ft. per shift.
Base rate of progress 3.5 ft. per shift.
Bonus footage 1.5 ft. per shift.
Bonus earned for per man = 1.5 ft. x 10 shifts x 25 cts. per ft. = $3.75.

Example 2.—1 shift working 10 days.

Total progress for period — 50 feet.
1 shift x 10 days = 10 shifts worked.
50 ft. ÷ 10 shifts = 5 ft. per shift.
Base rate of progress 3.5 ft. per shift.
Bonus footage 1.5 ft. per shift.
Bonus earned for period per man = 1.5 ft. x 10 shifts x 25 cts. per foot = $3.75.

BONUS SCHEDULE FOR TUNNEL WORK IN THE LITTLE LAKE DIVISION

Capacity of Tunnel	Class of Rock	Timbered or Untimbered.	Class of Work	Base Rate Per shift	No. of Men Per Shift	Rate per Man Per Bonus Foot
430 sec. ft.	Soft	Untimbered	Hand	4.5 ft.	9	20 cts.
430 sec. ft.	Soft	Timbered	Hand	4.5 ft.	9	20 cts.
430 sec. ft.	Hard	Untimbered	Hand	2.5 ft.	10	25 cts.
430 sec. ft.	Hard	Timbered	Hand	2.0 ft.	10	25 cts.
430 sec. ft.	Hard	Untimbered	Machine	3.0 ft.	11	30 cts.
430 sec. ft.	Hard	Timbered	Machine	2.3 ft.	11	30 cts.
430 sec. ft.	Hard	Untimbered	Machine	3.0 ft.	11	40 cts.
430 sec. ft.	Hard	Timbered	Machine	2.3 ft.	11	40 cts.
430 sec. ft.	Hard	Untimbered	Machine	5.0 ft.	14	30 cts.
430 sec. ft.	Hard	Timbered	Machine	4.3 ft.	14	30 cts.

BONUS SCHEDULE FOR TUNNEL WORK IN THE ELIZABETH TUNNEL, NORTH AND SOUTH PORTALS

Class of Rock	Timbered or Untimbered	Class of Work	Base Rate Per Shift	No. of Men Per Shift	Rate per Man Per Bonus Foot
Hard	Untimbered	Machine	2⅔ ft.	16	40 cts.
Soft	Timbered	Machine	2 ft.	23	40 cts.

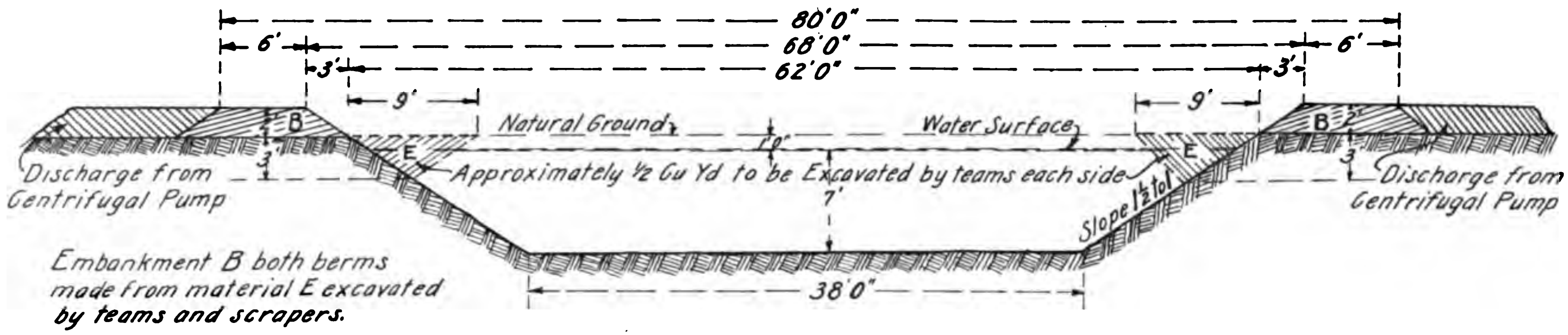
Noteworthy achievements in tunnel driving by the Aqueduct organization were at Tunnel 17-M, which is in a soft sandstone at the head of the Red Rock Canyon, where a tunnel 10,596 feet in length was excavated in seven months from two headings. As far as known the driving of 1,061.6 feet in the month of August, 1909, is the world's record for fast tunnel driving for one month's run. This tunnel was completely lined in eight months. In other words, this two-mile tunnel was driven and lined in a year and a quarter.

One hundred and sixty-four tunnels were excavated, and practically all of them were driven from two or more headings. There was not an error in instrumental work, either in line or grade, in any of the tunnels, or elsewhere on the work.

ELECTRIC DIPPER DREDGE CUTTING DIVERSION CANAL

UNLINED CANAL

Intake to Alabama Hills



Main canal excavation made by two centrifugal and one dipper dredge.

CONSTRUCTION QUANTITIES

Per lineal foot of conduit normal section.

Excavation 14.81 Cu. Yds.

HYDRAULIC PROPERTIES

S =	.0001895
V =	2.36
Q =	801
A =	339.5
P =	63.24
R =	5.37
n =	.027
C =	74.0

This form of Construction extends from the Aqueduct Intake to the North Toe of the Alabama Hills, a distance of 23.72 miles.

ENGINEERING DESCRIPTION OF CONDUITS

Unlined Canal

For a distance of 23 miles, from the intake of the Aqueduct to the north end of the Alabama Hills, the conduit consists of an unlined earthen canal of over 800 second feet capacity, 38 feet wide on the bottom and 62 feet wide on the water line. The constructed line is in the moist bottom lands of the Owens Valley, where the prevailing elevation of the ground water plane is from 2 to 4 feet beneath the surface. As the canal has an average depth of 10 feet, it would have been difficult and expensive to line it with concrete because of this ground water. Moreover, the canal will gain in flow rather than lose in passing through this division. Measurements show that 7 second feet, or 350 miner's inches, of water is constantly seeping into this canal, between the intake and George's Creek, exclusive of the 23 second feet from Black Rock Springs.

In view of this fact and because of the necessarily flat gradient (1 foot to the mile) and correspondingly large cross-section, this type of construction was adopted. The cost of this work is also very low.

The excavation was done by floating dredges. Dredges Nos. 1 and 2 were of the suction type, and were the first put in operation. Dredge No. 1 worked south from Black Rock Springs until it struck a heavy lime or travertine deposit opposite Sawmill Creek. This deposit extended for a distance of about a mile, required heavy blasting and could not be excavated by suction dredges. A dipper dredge was used to complete this section. It proved so efficient in its operation that it was decided to complete the canal with this dredge, and one of the suction dredges was dismantled and sent to the cement plant at Monolith, while the other was retained on the canal for maintenance work in the future. All the dredges were operated electrically and supplied with energy from the Aqueduct hydro-electric power plants at Division and Cottonwood Creeks.

The excavation amounted to 15 cubic yards per running foot and was accomplished at an average cost of $1.79 per lineal foot for all operating charges. The total cost, including administration, equipment, bridges, buildings and roads, and all auxiliary charges, was $2.83 per lineal foot for this type of construction. The suction dredges excavated a total of 41,540 feet at an average cost of $3.09 per lineal foot for direct charges, and the dipper dredge excavated 70,090 feet at an average cost of $0.81 per lineal foot.

Open Lined Canal

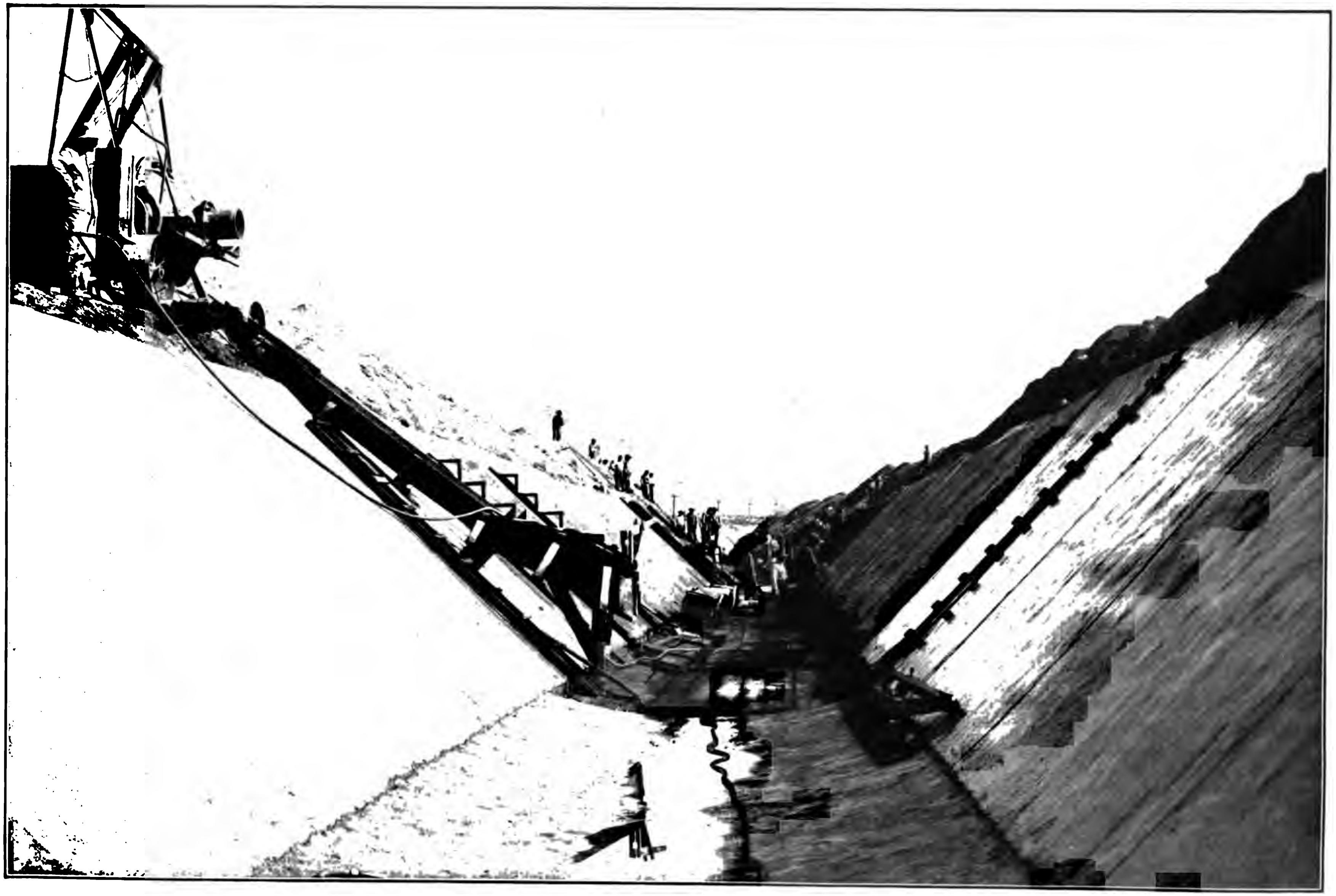
The unlined canal through the Owens Valley division ends at the north end of the Alabama Hills. At this point the open lined canal is started and extends to the south through the Olancha Division to the Haiwee Reservoir. From the end of the unlined canal the valley floor starts to fall away from the grade of the Aqueduct, and for 15 miles the line is well up on the face of the Alabama Hills, with occasional detours around large fans of coarse bowlders, which have been washed down from the canyons. From the south end of the Alabama Hills the line follows around a series of debris fans, ranging in structure from loose desert soil to bowlders of large size, more or less cemented, and reaches the reservoir 61 miles below the intake.

The ancient beach line of Owens Lake is closely followed by the constructed ditch. The lake, at the time this beach line was formed, stood at an elevation of 3,790 feet, or 220 feet above the present lake level. Although this was advantageous to the construction in providing an ample supply of clean, well-graded beach gravels for concrete, in close proximity to the work, it operated against it in that the excavation was carried through the detrital fans of the tributary canyons. At the time the lake was at the elevation of this ancient beach line, the country was subject to violent cloud-

UNLINED CANAL CONSTRUCTION IN OWENS VALLEY—DIPPER DREDGE OPERATED BY ELECTRIC POWER

STEAM SHOVEL EXCAVATION IN BOWLDERS, OWENS VALLEY DIVISION

CONSTRUCTION OF OPEN LINED CANAL IN OWENS VALLEY



PLACING CONCRETE LINING IN OPEN CANAL

OPEN LINED CONDUIT IN OWENS VALLEY, SHOWING OWENS LAKE IN BACKGROUND

bursts, and the tributary canyons discharged large quantities of water. This water washed down great bowlders and carried large quantities of debris. As soon as the stream entered the lake the velocity was checked and the debris deposited, the large bowlders along the shore line and the smaller material further into the lake bed. These bowlders and detritus, in the course of time and through the action of lime and calcareous deposits, in many places have become cemented into a form of conglomerate. It was with difficulty that the ditch was excavated in this material, bowlders as great as 10 to 30 feet in diameter having to be moved.

Concrete Lining

Owing to the porous nature of the ground through which the ditch was built, it was necessary to concrete it. The side slopes were made flat (1 to 1) so that the concrete could be placed without forms. The canal is located so that it is entirely in cut. The upper wall is well below the ground surface and the lower wall has not more than three feet of backfill. In some few cases, however, where the top cut was as high as 70 feet, the lower wall was built against three to five feet of backfill.

Owing to the large capacity (900 second feet) and necessarily flat gradient (0.15 feet to 1,000) it would have been somewhat impractical and very expensive to have covered this portion of the Aqueduct.

It will be noted that the open lined conduit has a larger capacity than the unlined canal. This is to provide for the waters of mountain streams which are crossed by the Aqueduct. Much has been done to provide for the safe delivery of the water from these side streams over and into the Aqueduct, and to prevent the overtopping of the walls by any sudden rise in the water level in the Aqueduct itself. At Cottonwood Creek an arch crossing for flood waters was built, and weirs were constructed so that this large creek can either be taken into the Aqueduct or passed on down the stream channel. Precautions have been taken for eliminating the sand and gravel from the water before it enters the ditch. Just south of this structure a standard waste-way was constructed, which permits of the turning all the water from the Aqueduct into the channel of the Cottonwood Creek, if desired.

Steam and Electric Shovels

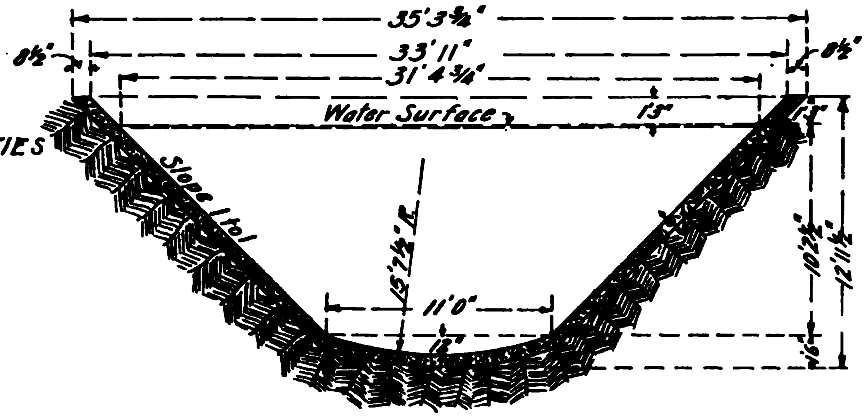
The ditch in this division was excavated by power shovels. One electric shovel and several steam shovels were purchased to start work. The materials excavated can best be divided into four classes; first, the loose desert soil; second, bowlders of medium size (up to 5 feet diameter) more or less cemented; third, extremely large bowlders, loose or cemented; and fourth, cemented gravel or solid rock. All these classifications were encountered separately and in combination, either in level cutting or on steep slopes. The yardage per foot ranges from 8½ cubic yards minimum to as high as 30 cubic yards on the side-hill.

In the desert soil the steam and electric shovels operated at the same cost of about 10 cents per cubic yard excavated. In the second class of work, in bowlders up to about 5 feet in diameter, more or less cemented with a hard indurated clay or gravel, the steamers operated at an average cost of 18 cents per cubic yard excavated. The electric shovel could not dig this material without having it shot up in advance at a cost of 11.4 cents per cubic yard, making the total cost for the electric shovel an average of 28 cents per cubic yard, or 10 cents per yard more than it cost with steamers in the same ground. No attempt was made to use the electric shovel in the more difficult classes of work. At places, granite boulders 10 to 20 and even 30 feet in diameter were encountered in large numbers. The steam shovels themselves were able to push boulders weighing from 8 to 10 tons out of the excavation.

Where deep side-hill cuts were encountered, it was found advantageous to use two steam shovels in tandem, one working ahead of the other, cutting down the upper half of the slope and throwing it down to the lower shovel, which would cut out the canal excavation and throw the material from the first shovel on down the side-hill.

OPEN LINED CANAL

Alabama Hills to Haiwee Reservoir



HYDRAULIC PROPERTIES

S =	.00015
A =	223.57
P =	39.91
R =	5.60
V =	4.03
Q =	901
n =	.014
C =	139.2

CONSTRUCTION QUANTITIES

Per lineal foot Normal Section.

Excavation	10.57 Cu. Yds.
Concrete	0.813 Cu. Yds.

COVERED CONDUIT

Mojave Division

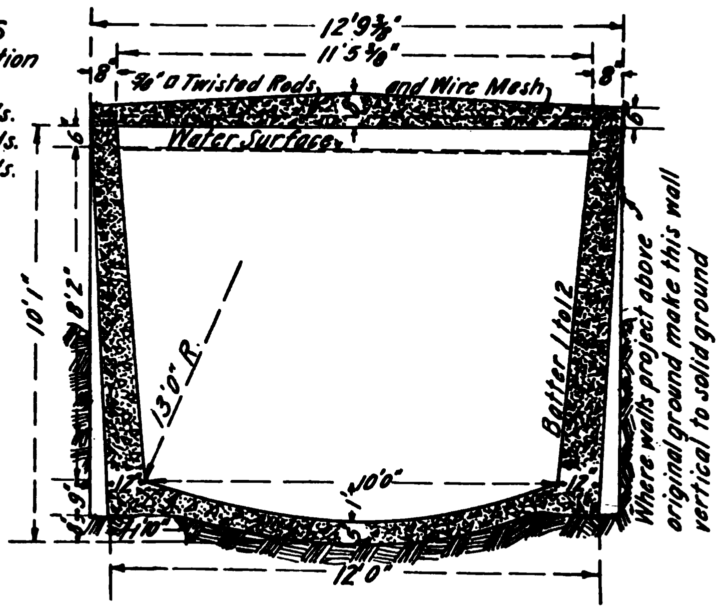
CONSTRUCTION QUANTITIES

Per lineal foot of Conduit Normal Section

Excavation	4.23 Cu. Yds.
Concrete in Conduit	0.536 Cu. Yds.
Concrete in Cover	0.280 Cu. Yds.
Steel in Cover	13.75 Lbs.

HYDRAULIC PROPERTIES

S =	.00035
A =	93.95
P =	26.65
R =	3.53
V =	4.59
Q =	431
n =	.014
C =	130.7



STANDARD TYPE OF OPEN LINED AND COVERED CONDUIT SECTIONS

Concreting was carried on immediately behind the shovels. An abundance of good clean gravel was obtainable from the ancient beach line of Owens Lake. The concrete lining on the sides was put on the 1 to 1 slopes in 6-foot sections without forms, and the bottom floated in and formed with templates. The sides were plastered. Tufa cement from Haiwee was used on all this work, and very satisfactory results were obtained with it when weather conditions were favorable. It was found necessary, during the winter months, to carefully guard the concrete from freezing during the night. This was accomplished by heating in boilers the water with which the concrete was made, in order to take the chill off and to speed up the setting time of the concrete. After the warm concrete was placed, it was covered with 2-inch planks to retain the heat and prevent the frost from affecting it.

The average cost per foot of conduit in this division was $8.38 for direct charges. The total average cost of the completed waterway, including administration, roads, bridges, wastegates, and all auxiliary charges, was $11.15 per lineal foot. The cost was very low when the difficulties of the work and its remoteness are considered.

Standard Conduit Section

From the Haiwee Reservoir the water is carried a distance of 135.26 miles to the Fairmont reservoir in closed conduits. The standard type of desert conduit differs from that originally proposed by the Board of Consulting Engineers in that it is covered and that the bottom is flatter. With the bottom sharply curved, the expense of trimming after the shovel and forming would be considerable. An uncovered conduit was not desirable in the desert divisions, but in the opinion of the Board of Consulting Engineers funds were not available to build it. A test mile of covered conduit was built near Mojave, and from the cost data thus obtained it was decided to cover all conduit of this character. This was done at a cost within that estimated for the uncovered conduit.

All the excavation of the 430 second-foot conduits was made with Model 40 Marion steam shovels, carrying ¾ yard dippers and booms 25 feet in length. The normal width of excavation was 12½ feet and the normal depth 10½ feet. The maximum curvature on which these shovels could work was for a radius of 72 feet, and this controlled the location. It was found desirable to waste all of the excavated material on one side of the ditch where possible, so as to leave the other side clear for the handling of materials for the lining.

The first portion of the standard 430 second foot conduit was built on the Mojave division near the Southern Pacific Railroad crossing. The location, in order to avoid deep cuts, was made normal on the ordinary slope of the plain and occasionally, in crossing swales or washes, the top of the conduit was permitted to stand up a foot or less above the ground elevation and the material was subsequently backfilled. A few storms indicated the defects of this class of location. Even if the top of the Aqueduct did not project more than a few inches above the bottom of the wash, it offered the opportunity for a slight drop and swirl in the storm water, which quickly eroded a hole of perhaps 2 or 3 feet on the lower side of the ditch, which it was necessary to riprap on the lower side. Other following storms still further aggravated this situation until the riprapping became burdensome. With this demonstration, it was decided to re-locate all the remaining unconstructed portions of the line so that either the Aqueduct should be completely imbedded beneath the normal surface of the ground in all swales or washes, or the crossing should be made so high that the required culvert room could be obtained underneath. As the work progressed, fewer culverts were used, as it was found difficult to keep them clear. Siphon culverts were unsatisfactory. High fills were avoided as much as possible. Where unavoidable, they were made by teams and then soaked down, and when the concrete was placed, the side walls of the conduit were carried down through the fill to the original ground elevations. The bottom soil was then again soaked, and the concrete bottom placed between the

side walls, the whole structure being thoroughly reinforced. There is not a total of a quarter of a mile of fills on the entire line.

Cost of Excavation

Generally speaking, ditch excavations were made in desert soil at from 8 to 10 cents per cubic yard for field construction charges proper and exclusive of auxiliary expenses of equipment, pipe lines, roads, etc. On side-hill work, where rock prevailed near the surface, the effort was made to locate the line so that the top of the rock on the down-hill slope would be approximately at hydraulic grade and in no place more than two feet below hydraulic grade. Excavations were made at prices ranging from 35 to 45 cents per yard, in fairly hard granitic rocks.

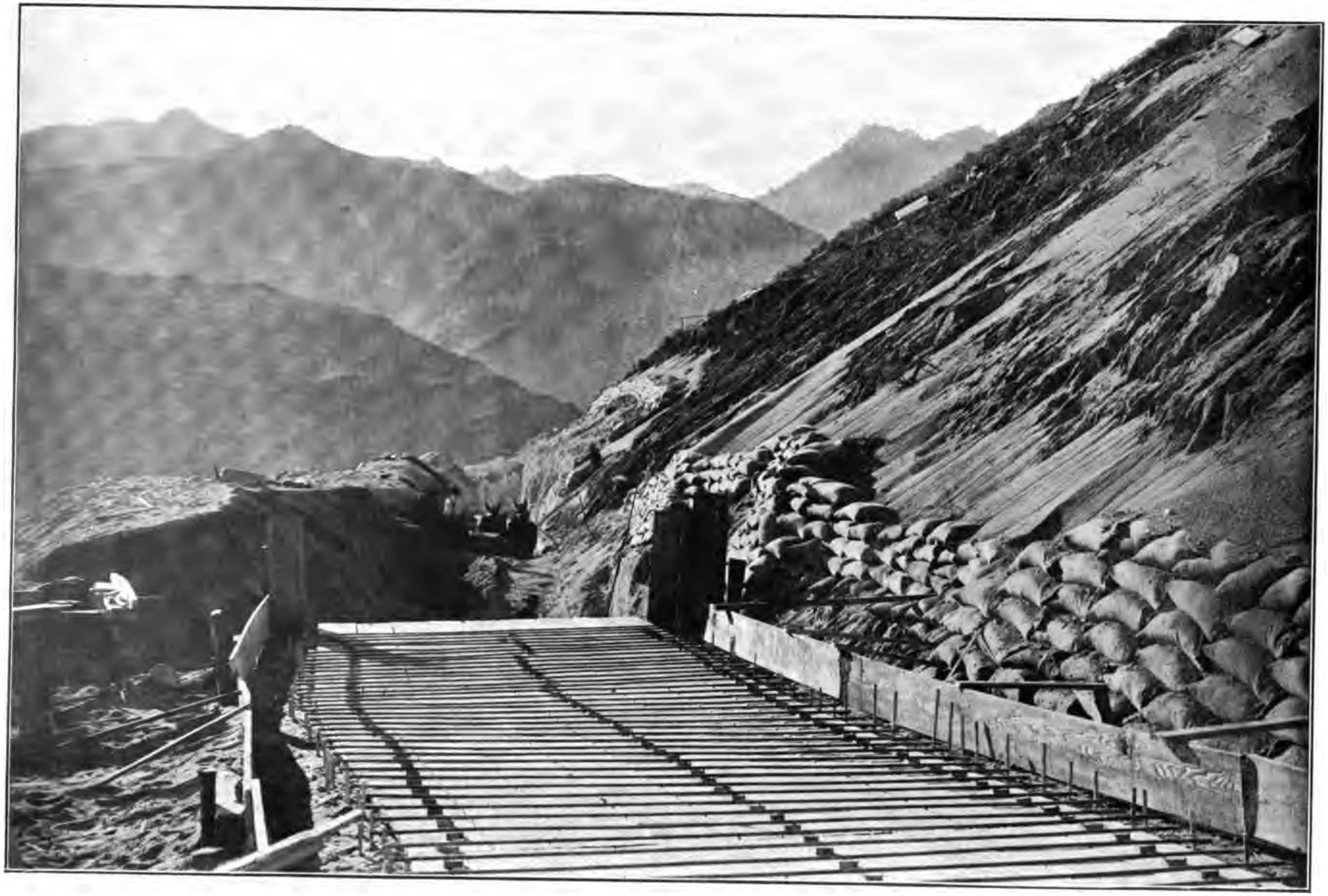
The shovels stood a most remarkable amount of punishment in this excavation. The dipper teeth used were of manganese steel. The shovels were standardized, the Model 40 Marions being used on the standard 430 second-foot conduits, and the Model 60's on the larger open lined conduits in the Owens Valley. A large supply of repair parts was kept on hand, and within a few hours after any breakdown it was possible to have the repair parts on the job and usually within 24 hours any ordinary repair could be made. Well equipped machine shops were maintained on every division. Electric power was available for the operation of these shops. To avoid delay to the concrete work, the excavation was maintained 500 feet in advance.

Conduit Cover

The first few miles of conduit were built with a concrete roof that was tied into transverse ribs on top of the cover. These ribs were 3 feet apart, center to center, with a maximum height of 15 inches in the center, and 5⅛ inches thick. The roof slab proper was but 3 inches thick, reinforced with wire mesh. After casting, the slab itself was covered with earth and the rib with sacks, all of which were wet down with a hose. It was found that while the earth could be kept moist, the sacks would dry out in a few minutes and the rib would cure at a different rate from the slab. This inharmonious curing of the rib and the slab had a tendency to produce shrinkage cracks at the connection between the rib and the slab, and largely for this reason the type of cover was changed and a flat slab substituted, which was 6 inches thick on the sides and 7 inches in the center. The same amount of reinforcing was put into this flat slab as was used in the ribbed cover, and a slightly greater quantity of concrete. Twisted rods ⅝ in. square were placed 18 inches apart where the roof slab was flush with the surface of the ground. Clinton triangular wire mesh fabric was also used, the rods being placed below the fabric and one inch above the bottom of the slab. Where the cover was 4 feet beneath the surface of the ground, the rods were placed 9 inches apart and where the cut was 6 feet excess, the rods were placed 6 inches apart.

The greater portion of the material encountered in the desert excavation was a clay loam, which would stand vertically, and where the ground was of this nature little reinforcing was used in the sides. Where the soil was sandy and would not stand up, backforms had to be used and the concrete sides were reinforced. The conduit is under greater stress during the period when it is empty than when it is full, because when rains occur and the ground becomes saturated, a hydrostatic pressure is set up on the outside of the wall without any balancing interior pressure. This was indicated in some places by longitudinal cracks showing up in the side walls, usually at a depth of about two-thirds the way down. When these cracks appeared serious, an excavation was made outside of the wall and a slab of reinforced concrete placed outside. In a few cases, where the walls were green and after the forms had been removed, when heavy rains occurred, there were failures in these walls, and for this reason the practice of reinforcing the side walls was adopted. The reinforcing rods used for the sides were allowed to project up about two inches so that the top was tied into the side walls. In addition, twisted wire keys 8 inches long, were set into the soft concrete top of the side walls before the casting of the roof. A concrete shoulder about 2 inches wide was also cast in the corners of the roof as a brace for the side wall on each side.

CUT AND COVER WORK ON STEEP SLOPE IN MOUNTAIN DIVISION



COVERING CONDUIT WITH CONCRETE ROOF

STEAM SHOVEL EXCAVATING TRENCH FOR CONDUIT

TRENCH DIGGING IN DESERT SECTION FOR COVERED CONDUIT

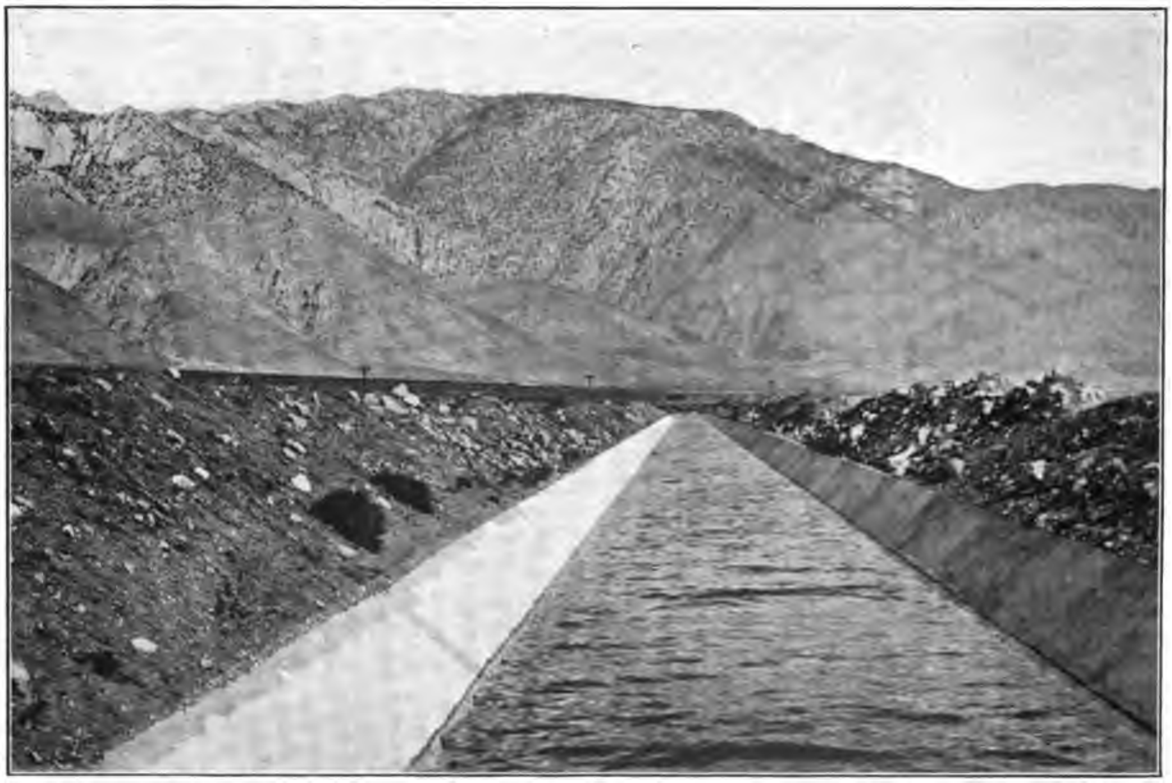
TRENCH DIGGING IN DESERT SECTION FOR COVERED CONDUIT

CONSTRUCTION CAMP AND CONDUIT TRENCH IN DESERT SECTION

COVERED CONCRETE CONSTRUCTION IN DESERT DIVISIONS

CONCRETE FLUME CROSSING THE FREEMAN WASH

COTTONWOOD CREEK CROSSING THE AQUEDUCT



OPEN LINED CANAL IN OLANCHA DIVISION

Careful cost data were kept from the start of the work, and the most economical location between conduit and tunnel was soon developed. It was found that on divisions where any one class of work predominated, it was very expensive to change the class of construction. Therefore, the divisions were adjusted to keep the various classes of construction separated, and when steam shovel conduit work was begun on a division, so far as possible any change in the class of construction was avoided.

Plaster Lining

All of the concrete lined portion of the Los Angeles Aqueduct was plastered, in order to obtain the most favorable possible coefficients of flow in the conduit. A number of interesting points developed in this plastering. It was observed that concrete will expand and contract with wetting and drying, and will keep this up indefinitely. An uncovered canal, or one in which the placing of the cover is delayed after the side walls are built, will develop transverse cracks at intervals of 30 or 40 feet, but if the cover is cast monolithic with the side walls and water is maintained on the invert, a humid condition is maintained in the interior of the structure, thus insuring a good curing of the concrete. In order to accomplish this, all the manholes have to be kept closed, and if this condition is maintained the shrinkage cracks will not occur. Mile after mile of covered conduit was built in this manner without a transverse crack showing up. If, however, the manholes were left uncovered and the wind was allowed to blow through the Aqueduct, the transverse cracks would appear and continue until water was put into the ditch, when the concrete would again swell and the cracks close. It was found by experiment that rich concretes have a greater coefficient of expansion due to wetting than lean ones, and that a plaster in which the ratio of cement to sand was the same as the ratio of the cement to sand in the concrete would adhere better and be less liable to scale than a rich plaster. The concrete generally used on the Aqueduct was a 1-3-6 mix, and the best results from plastering were obtained with a mortar composed of 1 part of cement to 3 parts of sand. The plastering cost from 1½ to 2 cents a square foot for labor and material. In the uncovered portions of the canal, during freezing weather, a great deal of difficulty was naturally encountered in getting plaster that would permanently adhere to the work. While most of the plaster properly adhered, there are sections where it is not sticking, and after the concrete has once aged, it is difficult to repair it.

Culverts and Flumes

In locating tunnels on the Aqueduct, it was at first thought necessary to provide free dump room for the muck, and this resulted in leaving an opening between tunnel portals, in a rough country, of two or three hundred feet. These openings occurred in ravines or canyons, and involved subsequent construction of flumes or of canals with culverts to connect the portals. This usually resulted in an increased cost of work. The Jawbone division, which was the one on which construction work on a large scale was begun, was located on this theory. On other divisions this practice was discontinued. The opening between portals offers a point of attack for surface or flood waters. Where the line between portals was located in covered conduit, a large culvert had to be built at the crossing of the drainage line. Almost invariably the tunnel dump encroached on the canyon opening to such an extent that this culvert location became blocked. and the dump had to be excavated for the purpose of building it. The culvert is a danger point on a line. The experience gathered on the Aqueduct shows that as a rule a cheaper and better location can be obtained, in a division where tunnels predominate, by throwing the tunnel completely back under the mountain and making the location in such a way that adits or drifts can be driven into the tunnel line at intervals for the purpose of taking out the muck and handling material for the lining. When the tunnel has been driven and the lining completed at other points, the adit can then be closed with concrete, and the line is safe from the attacks of flood waters. This adit, provided it is not more than 100 feet in length, is less expensive than the culvert.

CONSTRUCTION OF INVERTED SIPHONS OF STEEL PIPE AND REINFORCED CONCRETE

There are 23 inverted siphons where the located line of the Aqueduct crosses canyons and valleys, totaling 11.4 miles in length. Eight of these siphons, comprising 2.7 miles, are 10-foot diameter, reinforced concrete pipes, operating under heads up to 75 feet; the remaining siphons are steel pipe ranging in diameter from 7 feet 6 inches to 11 feet 6 inches, and in thickness of metal from ¼ inch to 1⅛ inches.

The first two siphons built were those at Dove Springs and San Antonio Canyons. These are comparatively short pipes. A contract was awarded to the Lacy Manufacturing Company for their fabrication and erection. These are the only pipes that were erected by a contractor, and the only ones laid in trenches deeper than the diameter of the pipe, the siphons built subsequent to these being on piers, or on the ground in shallow trenches. The cost for trenching and bell holes was found to offset the cost of piers.

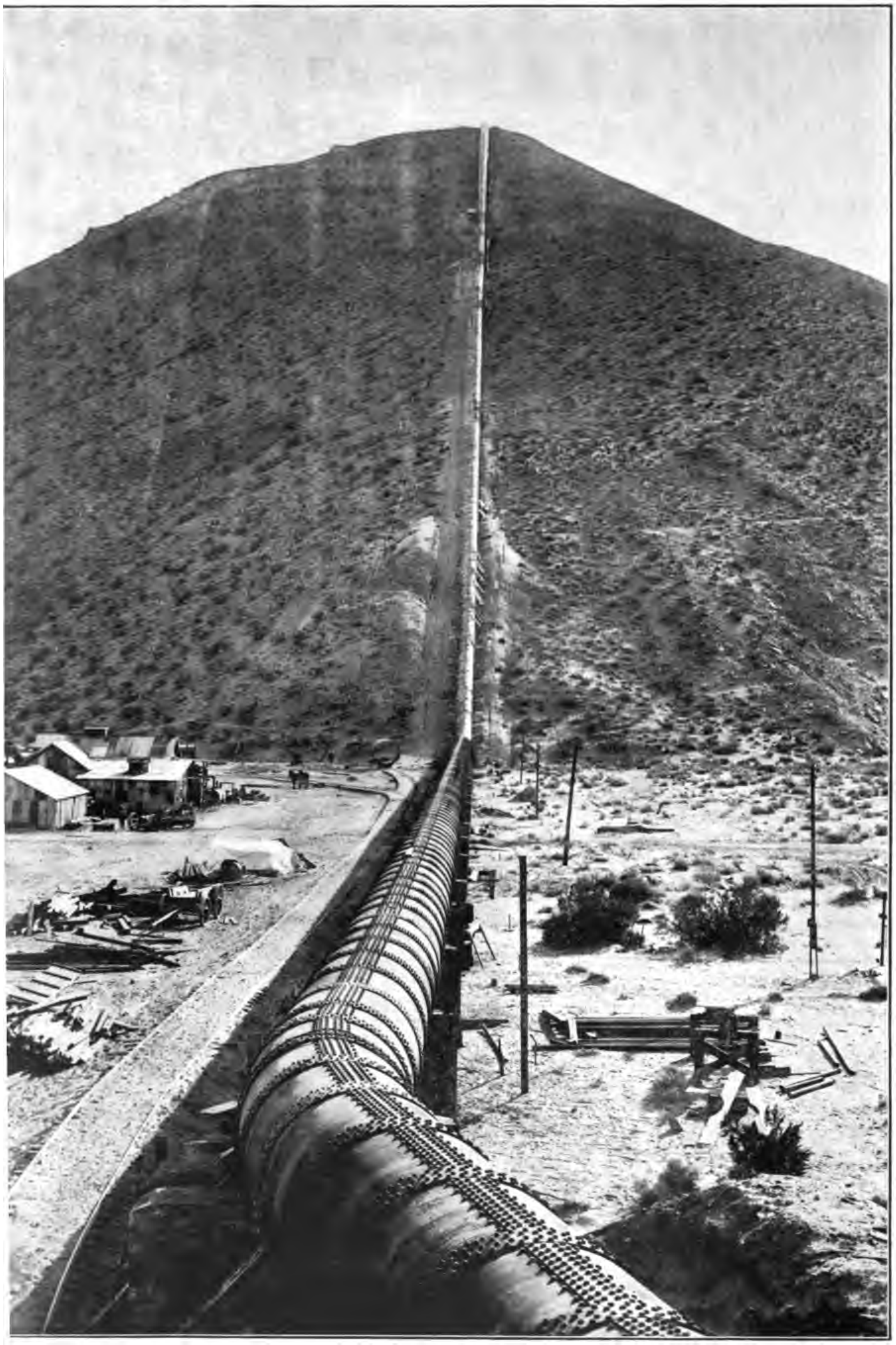
Specifications

Specifications were issued for the materials for other siphons at three different times. First, the steel and rivets for the Nine-Mile Canyon Siphon at the south end of the Little Lake Division. This was awarded to the Camden Iron Works, at 1.9733 cents per pound, f. o. b. Camden, New Jersey. The second specifications included the No-Name Canyon siphon in the Grapevine division, and Deadman, Soledad, Quigley, and Placerita Canyon siphons in the Saugus division. This contract was awarded to the Treadwell Construction Company at 1.6983 cents per pound, f. o. b. Midland, Pennsylvania. The third set of specifications included the Sand Canyon and Grapevine Canyon Siphons in the Grapevine division; the Jawbone and Pine Tree Canyon Siphons in the Jawbone division; and the Antelope Valley Siphon in the Antelope division. The aggregate weight of these siphons was 9,555 tons, and the contract was awarded the Riter Conley Manufacturing Company at a price of 1.4857 cents per pound, f. o. b. Pittsburg, Pennsylvania.

Each siphon was itemized in the specifications, and bids were received on each separate item and a lump sum bid for all items. Alternate bids were received on single-plate construction and two-plate construction, as it was thought that the two-plate construction might be less expensive, owing to the large plates required for the big pipes. In every instance, however, the bids were lower for the single-plate construction.

Unusual or special specifications for steel plates were avoided in order that the lower prices of standard material could be obtained. The specifications of the American Society for Testing Materials, for boiler plate steel, which are the standard requirements adopted by the steel manufacturers for stock material, were accepted by the Aqueduct officials. Years of experience in the Los Angeles City Water Department have demonstrated that this class of steel is satisfactory for riveted steel pipe construction, both as to workmanship and reasonable lasting qualities in the ground. Some tests were made of the corrosion of American Ingot iron plates, but it was found that while this class of pure iron would resist deterioration from acids better than steel, in the alkalies, such as are contained in our southwestern soils, it had no advantage, and the price was substantially higher.

The plates purchased by the Aqueduct in 1912 were bought, rolled and punched, in the eastern market. The pipes that were laid by contract in the Dove Spring and San Antonio Canyons weighed 262 tons and cost the City 4.265 cents per pound in place. However, on the two small contract pipes the City did the hauling, furnished power free for purposes of



SOUTH END OF JAWBONE SIPHON

erection, and supplied the air under pressure for riveting, so that the completed pipes under contract cost the City fully 5 cents per pound in place, which was approximately 25 per cent. more than the work that was done by day labor.

The thickness of the metal in the pipes was fixed by a unit stress of 15,000 pounds on the gross section. All plates over ½ inch in thickness had triple riveted butt joints, with edges planed, and were shop riveted together in two-ring sections, except the heavy plate across the bottom of the canyons, which were shipped riveted in longer sections. Plates ½ inch or less in thickness had lap joints with edges sheared for outside caulking, and were rolled and punched, all rivets being driven in the field. Drawings were included in the specifications, showing the joint required for each thickness of plate, the plan and profile of the pipe giving its definite location as to line and grade.

Owing to the isolation of the construction work from any shop facilities, precaution was taken to eliminate possibilities of error. The successful bidder was required to submit to the office of the Chief Engineer detail drawings showing the proposed method of construction of all angles, transitions between butt and lap joints, and typical transitions between different diameters of pipe and thickness of plate, together with the regular straight section of pipe for all thicknesses of plate and diameters. Diagrams of each siphon were furnished, drawn to a sufficiently large scale to show the position of each section of pipe. These drawings were all carefully checked in the office of the Chief Engineer. It was required to show their position in the completed pipe. The material was inspected at the shop before shipment, the metal analyzed and its physical properties tested. All dimensions and coincidence of rivet holes were checked by assembling. The result was satisfactory, as no errors were found. The pipe was shipped in flat cars in minimum carloads of 30,000 pounds to the nearest siding, and hauled from the siding by teams to the canyon.

Erection

With the exception of the Antelope Valley, which was a broad sloping plain, where the pipe could be delivered by wagons to the trench, the siphons were erected in mountainous canyons with steep side slopes. A variety of hoists were used for this class of work. In the No-Name and Nine-Mile Canyons, where rather small siphons were built, aerial cableways were erected with hoisting derricks, and the pipe lifted into position by cables. In the larger canyons, such as Jawbone, Pine Canyon and the Soledad, inclined railways were built and circular drum hoists installed at the tops of the siphons. Of the two methods of work the inclined tracks were the more satisfactory, especially for the heavier pipe, but the cableways worked satisfactorily for the lighter pipe. The heaviest section of built-up pipe was for the Jawbone siphon. It weighed 52,000 pounds and was 36 feet 10 inches long. It was shipped from the East built up, and was hauled into place by 52 mules.

For pipes as great as 10 feet in diameter, ¼-inch steel plate is the minimum thickness that properly can be used and obtain satisfactory rigidity. The ¼-inch plate gives satisfactory tensile strengths up to 144 feet of head with diameters of 10 feet. In the case of the Nine-Mile siphon, which is 9 feet 6 inches inside diameter, after the pipe was erected and when it was empty, the vertical diameter was 9 feet and the horizontal diameter 9 feet, 9¾ inches. With 50 pounds pressure this pipe measured a horizontal diameter of 9 feet 7 inches, and a vertical diameter of 9 feet 6½ inches. In the case of the Soledad siphon, which was 10 feet in diameter and with ½-inch plate, under a head of 260 feet, the horizontal diameter of the pipe was reduced 6 inches when the pipe was filled with water. This changing in the shape of the pipe must be taken into consideration if concrete piers are to be built around it.

The question of whether the pipe should be placed wholly in a trench, partly in trench, or on piers, is open to argument. The first pipe built on the Aqueduct was placed wholly in trenches. With a diameter of 10 feet and the necessity of making bell holes for riveting pur-

poses at intervals of at least 12 feet, the amount of excavation becomes very burdensome and in some locations may run as much as $10.00 a lineal foot. These pipes were laid, then filled with water, then backfilled and solidly anchored into the concrete work at either end, without any provision for expansion. There is no evidence either of leakage in the steel or of rupture in the concrete connections. The principal rusting of pipe in our southwestern soil is due to mineral salts in the soil, which become slightly moist with a small leakage in the pipe, and this facilitates the deterioration of the joints and rivet heads. When the pipe is completely buried in the trench, it is impossible ever to repaint it.

Pipe on Piers

Most of the pipes that have been constructed on the Aqueduct have been laid on piers. In order to determine the proper intervals between supports under these pipes, a section 10 feet in diameter was built of ¼-inch plate 100 feet in length, and steel bulkheads placed in the ends of the pipe. Supports made of 12x12 timbers were then placed under the pipe, and the pipe was filled with water. These 12x12 supports are more severe on the pipe than a concrete pier having a width of 2 feet and cast to fit the pipe. It was found that this experimental pipe could be sustained properly at intervals of 24 feet center to center. A case subsequently occurred in the field where two piers on the sidehill settled away from the pipe, leaving the supports 72 feet apart. The pipe was 11 feet in diameter and built of ¼-inch plate. This pipe when filled stood suspended without injury until the defective supports could be replaced.

At first, in designing the piers, it was considered necessary to build the sides up to the horizontal center of the pipe, and this was done with the first pipe built above the ground at the Nine-Mile canyon. It was found that this pipe, when empty, had a horizontal diameter 9 inches greater than its vertical diameter, and the effort was made to rectify this by putting stulls in the pipe while the piers were being built and prior to the filling. When the pipe became about two-thirds full, the stulls having been removed, the distortion was aggravated, and the leverage that it exerted on the sides of the pier was sufficient to rupture the piers on the lines radial to the pipe. A number of the sides were broken off, and in some cases the piers were split vertically through the center on a line with the axis of the pipe. These piers were two feet thick, one foot in width at the top and reinforced with six ⅝-inch round rods. The piers were carried up high on the sides in order to stiffen the plate on the sides of the pipe. After the pipe had been filled with water and had assumed its circular shape, it was noted that on these ruptured piers not over 3 or 4 feet of the circumference of the pipe was bearing on the pier. These observations led to the conclusion that the piers need not be built so high, that they should be larger in section, and that their strength should be such as to resist rupture on lines radial to the pipe. The pier should be built up to the level of the bottom of the pipe. The reinforcing rods should be left projecting up through the pier from the sides, which subsequently are to be completed. The pipe should then be laid and built on the partly constructed pier. It should be filled with water as soon as convenient, and after it has taken its proper shape, the sides of the pier should be cast. This practice gave the most satisfactory results.

Before the pipe is filled with water, there is longitudinal expansion and contraction, due to changes in temperature, and this movement back and forth on top of the piers is apt to check them on the edges. This is not a serious matter, and probably could be avoided by placing a thin sheet of metal on top of the pier. In the case of the Nine-Mile siphon, which has a total length of 1,435 feet and which was laid north and south across a canyon having slopes of approximately one foot vertical and three feet horizontal, a change of temperature in the air, as measured in the shade, from 58 to 92 degrees resulted in a lengthening of the pipe of 3¼ inches at the north end and 1-11/16 inches on the south end, which was the steeper slope. There was also a lateral movement between morning and evening of ½ inch. This was

NORTH END OF PINE CANYON SIPHON

FIFTY-TWO MULE TEAM HAULING THIRTY-TON SECTION OF JAWBONE PIPE

prior to the time when the pipe was filled with water. With piers 24 feet apart, some tendency of the pipe to flatten on the bottom, where it rested on the flat-topped pier, was observed, but this was not serious, and the pipe rounded out when put under a good head.

Pipe in Trench

The most satisfactory results were obtained on the Aqueduct by laying the pipe in a shallow trench that supports about one-third of the bottom circumference of the pipe. This can best be done on gentle slopes where the soil conditions are favorable.

It is desirable to cast heavy concrete blocks or to completely cover the pipe with an earth fill at angle points because of the tendency of the pipe to move longitudinally at these angles. Where the angle is vertical, dipping into the ground, this thrust is taken up by the earth or by the pier, but where the vertical angle is away from the surface of the ground, especially on the side-hills, the tendency is for the pipe to lift off the pier vertically during the warm hours of the day and then return to the pier during the cool hours of the night. There is one instance, and one only, on the Aqueduct, where this motion has taken place. These concrete anchorages, while expensive, are not prohibitive in cost.

Careful consideration was given to the advisability of rigidly anchoring the pipe into the concrete abutments at either end. The practice at first was to make a long expansion joint at the connection with the concrete. This joint lapped over one 6-foot plate. The opening between the concrete and the pipe at the inside end of the joint was ½ inch and at the outside one inch. These joints were packed with oakum. The head on the pipe at these joints ranged from about 3 to 13 feet. The concrete transition around the joint was of a massive character and heavily reinforced. It was found that in driving the oakum into the joint the plate would spring out of shape and away from the concrete further at one point on the circumference than at another, and that the joints nearly always leaked. After casting several of these joints, the practice was adopted of riveting angle irons around the outside circumference of the pipe, and casting massive concrete over the pipe for a distance of about 10 feet. This concrete was cast after the pipe had been filled with water. All of these joints have stood well. No rupture of the concrete has occurred and no rivets have ever been found to have been sheared by compression or tension. These connections have all been made in cool weather, the effort being to make the casting when the pipe was in a condition of minimum length.

No buckling occurred after the pipe was filled with water and anchored into the piers. There are no expansion joints in any of the steel plates.

The practice of purchasing the plates at the eastern mills rolled and punched, and erecting in the field, was entirely satisfactory. In the case of the San Antonio and Dove Springs pipes, which were let by contract, the contractor shipped the plates to the field and set up a small mill there to roll, cut and punch the plates. This work proved more expensive than that done subsequently by the City.

Bonus

On all pipes laid by the City, with the exception of the Jawbone and the first pipe built in Nine-Mile canyon, a bonus schedule was adopted for the riveting crews.

On the Antelope Valley siphon, on the Los Angeles Aqueduct, the crews averaged about 1,000 ⅝-inch rivets in one day. The conditions for work at this point were favorable, there being smooth ground to work on and the pipe being readily rolled into the trench. The practice was to rivet two rings or more together at the side of the trench, and then roll the two-ring section, 12 feet in length, into it. In riveting up these sections outside of the trench, as many as 1,615 rivets were driven by one crew in an 8-hour shift. Under the bonus schedule on the Antelope Valley siphon, about one-third more ⅝-inch rivets were driven than on the Jawbone pipe, where a bonus schedule was not applied, but where the riveters were paid 50 cents a day more than on the Antelope Valley siphon. On the Pine Canyon siphon, the riveters averaged about $1.50 a day of bonus money.

The foreman in charge of this work was an expert steel man, entirely competent to do the riveting himself and a man who was proficient in the handling of labor. It was his duty to inspect the riveting and to reject any defective rivets. This was rigidly done, and the crews were required to cut out any rivets that were defective.

On the Saugus division the following are the number of different sized rivets driven per crew per shift on the six siphons built in this portion of the Aqueduct:

1" rivets	293
⅞" rivets	377
¾" rivets	480
⅝" rivets	505

This is for an 8-hour shift.

On the No-Name siphon, which was in a very steep canyon, the average per crew per shift was as follows:

1" rivets	346
⅞" rivets	410
¾" rivets	623
⅝" rivets	797

These latter figures are computed from the actual number of hours rivets were driven during the entire job.

The bonus schedule is given below. Apparently it is too liberal on the smaller rivets and possibly too severe on the larger rivets.

BONUS SCHEDULE FOR RIVETING

Mechanic Employed as	No. of Men Per Shift	Size of Rivets	Wages per diem	Base Rate per Shift	Crew Bonus per Rivet	% of Bonus per Man per Shift
Riveter	1	⅝" ¾" ⅞" 1"	$3.50	500 Rivets 400 Rivets 325 Rivets 275 Rivets	$ .01½ .01¾ .02 .02¼	30%
Heater	1	⅝" ¾" ⅞" 1"	3.00	500 Rivets 400 Rivets 325 Rivets 275 Rivets	$ .01½ .01¾ .02 .02¼	30%
Bucker	1	⅝" ¾" ⅞" 1"	2.75	500 Rivets 400 Rivets 325 Rivets 275 Rivets	$ .01½ .01¾ .02 .02¼	20%
Sticker	1	⅝" ¾" ⅞" 1"	2.50	500 Rivets 400 Rivets 325 Rivets 275 Rivets	$ .01½ .01¾ .02 .02¼	20%

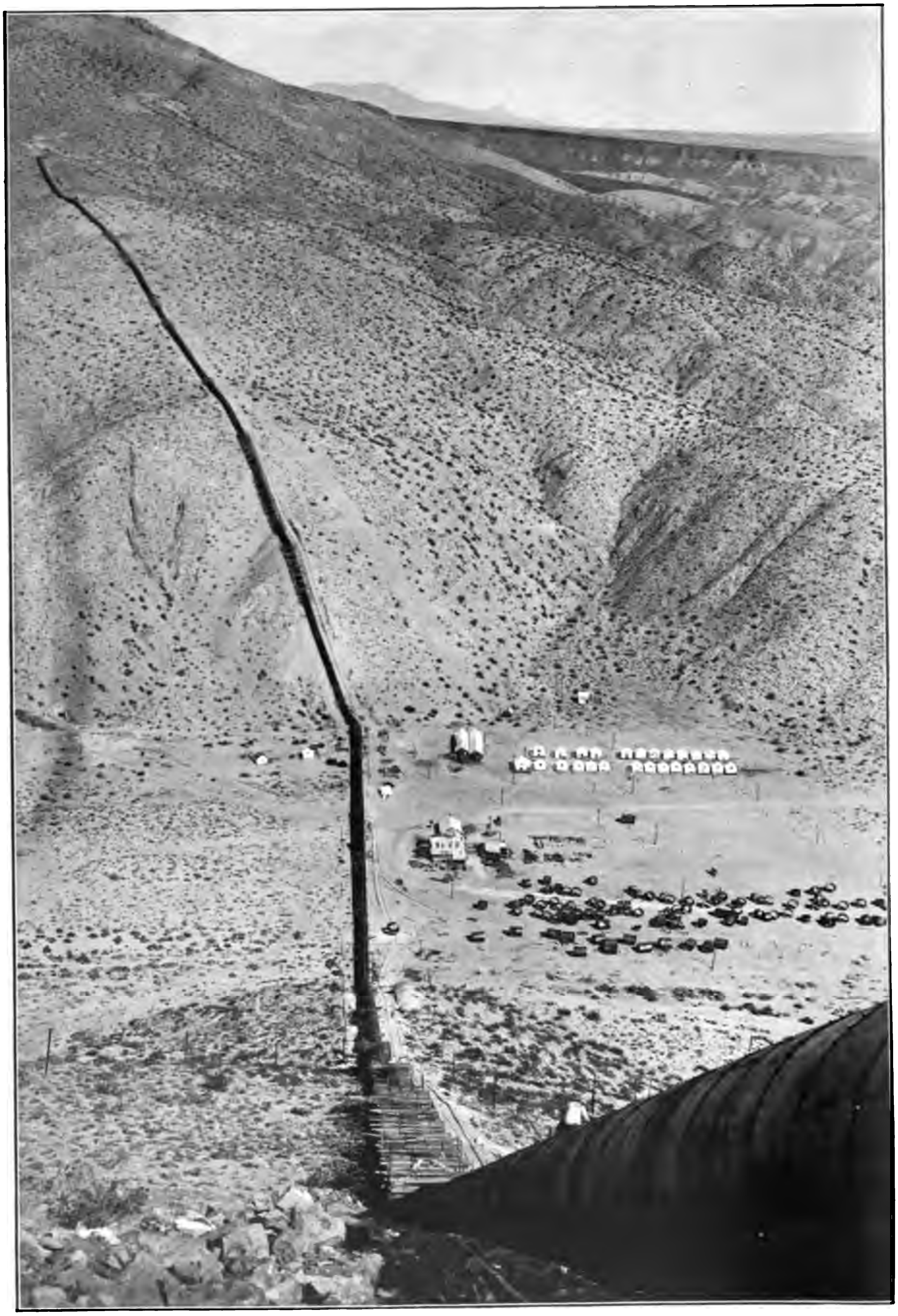
The following rules applied to the payment of bonus on the Pine Canyon siphon:

1. Ten days shall constitute a bonus period. The first period shall be from the 1st to the 10th of the month, inclusive; the second, from the 11th to the 20th, inclusive; and the third from the 21st to the end of the month. Bonus payments shall be allowed upon the basis of measurements made at the close of each ten-day period.

2. Only men who work continuously through the ten-day period, with the following exceptions, shall be entitled to bonus.

(a) Any employe, entitled to bonus earnings, who is injured or becomes ill during a period from conditions arising directly from siphon construction, shall participate in bonus in proportion to the number of shifts worked by him during said period.

(b) If any employe, entitled to bonus earn-



NORTH END OF JAWBONE SIPHON

Deadman Siphon Looking Due North, Showing Pipe Before Concrete Piers Were Placed. North End of Steel Pipe Connected with Concrete Pipe which Follows Windings of the Crest of Hill

Forms for Concrete Portion of Antelope Valley Siphon

Concrete Siphon in Whitney Canyon. Photograph shows wooden forms. These were supplanted on other concrete siphons by steel forms

ings, is transferred during a period to another part of the work for reasons other than his own request, he shall participate in bonus in proportion to the number of shifts worked by him on such construction.

(c) If the work is interrupted by the failure of power, shortage of material or supplies, or other causes beyond the control of the men, the men shall be entitled to bonus in proportion to the number of shifts worked by them during the period in which such interruption occurred.

Efficiency of the Bonus System

An excellent opportunity was offered for comparison of work done under the bonus system and work done without it in the erection of the Jawbone and Pine Canyon Siphons.

The Jawbone Canyon is next in position to the Pine Canyon on the Jawbone division. The division engineer, Mr. H. A. Van Norman, had charge of erecting siphons at both of these points. The steel plates and rivets for both these siphons were furnished by the same contractor, and consequently were of the same general class of material and accuracy of workmanship. Climatic conditions were the same, as both jobs were in progress together. Both sites are mountain canyons with broad washes at the bottom and steep side-hills on either end. The pipes in both cases were laid on piers. Electric energy was furnished from the same system for both pipes, so that when power was off at one place, the other camp was in a similar situation of service. The slopes are steeper and more difficult, though not so long or high, in the Pine Canyon than in the Jawbone Canyon.

Because of the large pressure head on the Jawbone siphon (850 feet), it was deemed advisable to eliminate the bonus schedule for this work on the theory that the work might be done more carefully. The completed jobs, however, show up practically the same, and both the pipes have been filled with water and both are satisfactorily tight. Both camps were in the immediate charge of pipe foremen, who had been on the work for approximately a year's time.

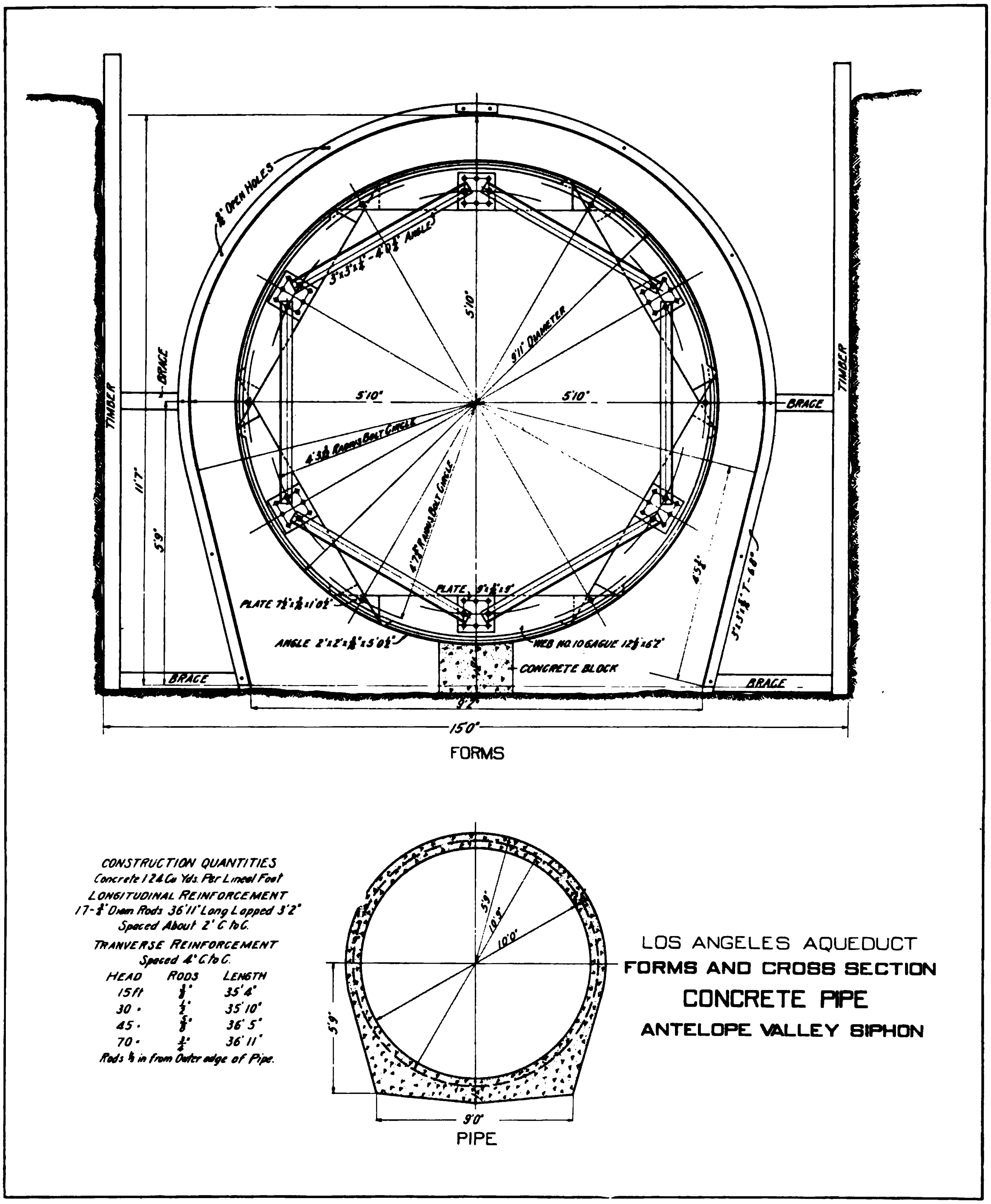
The Jawbone crew was the larger, and possibly broke in more new men on the work than the Pine Canyon crew. However, one of the features of the bonus system was that only men who worked continuously through the 10-day period should be entitled to bonus, and these men developed more *esprit de corps* than those who were simply working on a day labor basis. In order to obtain and hold good men on the Jawbone crews, who were not under the bonus system, the riveters were paid 50 cents per day more, the rest of the crew being paid the same wages as on the Pine Canyon siphon.

For the sake of making comparison between the work accomplished under the bonus system and under a higher wage schedule, the month of December, 1912, is selected for analysis on each pipe. During this month the work was under full swing, the unit cost ot riveting being the smallest on both jobs for this month and the largest number of rivets being driven. The thickness of the plates and the diameter of the pipe on the portions constructed at this time were practically the same. The following table shows the diameter of the rivets, the number of each size, and the percentage of the total number driven in this month for each siphon:

NUMBER OF RIVETS DRIVEN AT JAWBONE AND PINE CANYONS SIPHONS IN DECEMBER, 1912.

	Jawbone Siphon		Pine Canyon Siphon	
Diameter of Rivets	Number of Rivets Driven	Per Cent. of Total	Number of Rivets Driven	Per Cent. of Total
1"	8,170	10.6	2109	6.1
⅞"	2,682	3.5	2090	6.1
¾"	6,030	7.8	3767	10.9
⅝"	60,364	78.1	26410	76.9
	77,246	100.0	34376	100.0

The character of the work was similar, but fewer crews were worked on the Pine Canyon siphon than on the Jawbone siphon because the Pine Canyon siphon was the shorter pipe. In the Jawbone Canyon, 10 crews were working during December, and the number of rivets driven per crew was 7,725, the total riveting cost for the month being $4,376.79, and the average cost per rivet 5⅔ cents. In the case of the Pine Canyon siphon, there were three crews working, the number of rivets driven



STANDARD STEEL FORMS FOR REINFORCED CONCRETE SIPHON PIPES

per crew being 11,459, and the total riveting expense $1,150.48, or an average cost per rivet of 3⅓ cents. During the month 13,086 bonus rivets were driven on the Pine Canyon siphon, on which a bonus was paid averaging 1.56 cents per rivet. The average crew working under a bonus schedule on the Pine Canyon siphon drove 11,459 rivets during the month, and the average crew working without bonus, drove 7,725 rivets, or 3,734 less than the bonus crew. This shows an increased efficiency of the bonus crew of 48.4 per cent. As to cost, the rivets driven by the no-bonus crew cost 5⅔ cents, while the rivets driven by the bonus crew cost 3⅓ cents, or 2⅓ cents less, the saving due to the bonus schedule, according to these figures, being 41 per cent. of the cost of riveting at Jawbone. The crews in the Jawbone Canyon probably were not composed of as high grade men as those in Pine Canyon, although in paying more wages per day for the riveter on the Jawbone, the effort was made to get the most skilled labor for this more important pipe.

Broadly speaking, as the result of observation over the entire work, it is believed that the establishment of the bonus system resulted in a saving of from 25 to 50 per cent. in riveting costs.

The following table shows the total number of rivets driven by the three crews on the entire Pine Canyon siphon, the number of rivets on which bonus was paid, and the percentages of rivets of various sizes on which bonus was earned and the total amount of bonus distributed:

NUMBER OF RIVETS DRIVEN AND BONUS EARNED AT PINE CANYON SIPHON

Diameter of Rivet	Total Rivets Driven	Bonus Rivets	% bonus rivets to total driven of that diameter	Total Bonus Paid
1"	42,619	8,379	19.7	$209.47
⅞"	4,070	724	17.8	14.48
¾"	5,274	1,975	37.5	34.56
⅝"	40,836	19,851	48.6	297.76
	92,799	30,929		$556.27

This table shows that the average amount of bonus paid on all rivets driven was .6 cents, and that for the rivets driven in excess of the base number fixed in the schedule the crew received 1.80 cents bonus per rivet.

The average cost of the steel in place, including transcontinental freights, local freights, wagon hauls, engineering, equipment and supervision, covering all general field expenses, of approximately 4 cents a pound in a remote desert region demonstrates that this pipe work was economically accomplished.

Concrete Pipes*

There are 11 concrete pipes on the Los Angeles Aqueduct, all of which are 10 feet in diameter, and with heads ranging from 40 up to 75 feet. The reason for building concrete pipes was that they were estimated to be cheaper and better for heads less than 75 feet. This is approximately the pressure under which water will begin seeping rather freely through rich concrete. Quarter-inch steel plate for a 10-foot pipe, with the factor of safety used on the net section, as designed on the Aqueduct, has adequate tensile strength up to heads of 144 feet. As the strength of the concrete pipe is based wholly on the tensile strength of the reinforcing steel used in its construction, and not on the strength of the concrete in tension, there would have to be as much weight of steel in a concrete pipe for a 144-foot head as in a steel pipe, and the cost of the concrete is extra cost for concrete pipe above that of steel pipe for this head.

A series of tests of concrete pipe were made for the Reclamation Service in Los Angeles by Mr. J. H. Quinton in 195. The result of these experiments and tests is shown in Water Supply and Irrigation Paper No. 143 of the U. S. Geological Survey. This experimental pipe all had a diameter of 5 feet, a length of section of 20 feet and a thickness of 6 inches. A number of different waterproofing compounds were used, and the pipes were all plastered. A mixture as rich as 1 of cement, 2 of sand and 4 of gravel, was used. Mr. Quinton says, on page 56: "Do not use steel concrete pipes for heads over 70 feet, except for short distances, where a 100-foot head might be used by taking special precautions."

The forms used in the manufacture of this pipe were developed for this particular piece

*See Plate No. 21. Standard Type of Concrete Siphon—in map pocket.

of work. It was necessary to have a collapsible form that could readily be dismounted and loaded onto a car, which was pushed along on the inside of the pipe. This form proved entirely satisfactory and was used throughout for the construction of all the pipes. The panels were sheeted with thin galvanized iron in order to protect the lumber, which would otherwise curl up and split.

The concrete ends of siphon No. 9 and all of Nos. 10, 11, 11-A, 12 and 13 were made of Tufa cement from the Fairmont mill. The other pipes were made of straight cement. It is believed that the tufa cement pipe is more satisfactory than that made with straight cement, because the tufa cement is ground finer and therefore should be denser than the straight cement.

The mixtures used in the manufacture of this pipe were 1 of cement, 2 of sand and 4 of stone. In pipes Nos. 20 and 21, river-washed gravel was used, which would leave about 50 per cent. of stone on a ¼-inch screen. The thickness of the shell on the sides and top was 9 inches. With a head of 70 feet, this would give a tension of about 200 pounds per square inch on the concrete shell. From tests made with the materials used it was found that the concrete after attaining an age of one month, was fully strong enough or stronger than required to resist this tension without any of the load coming on the steel.

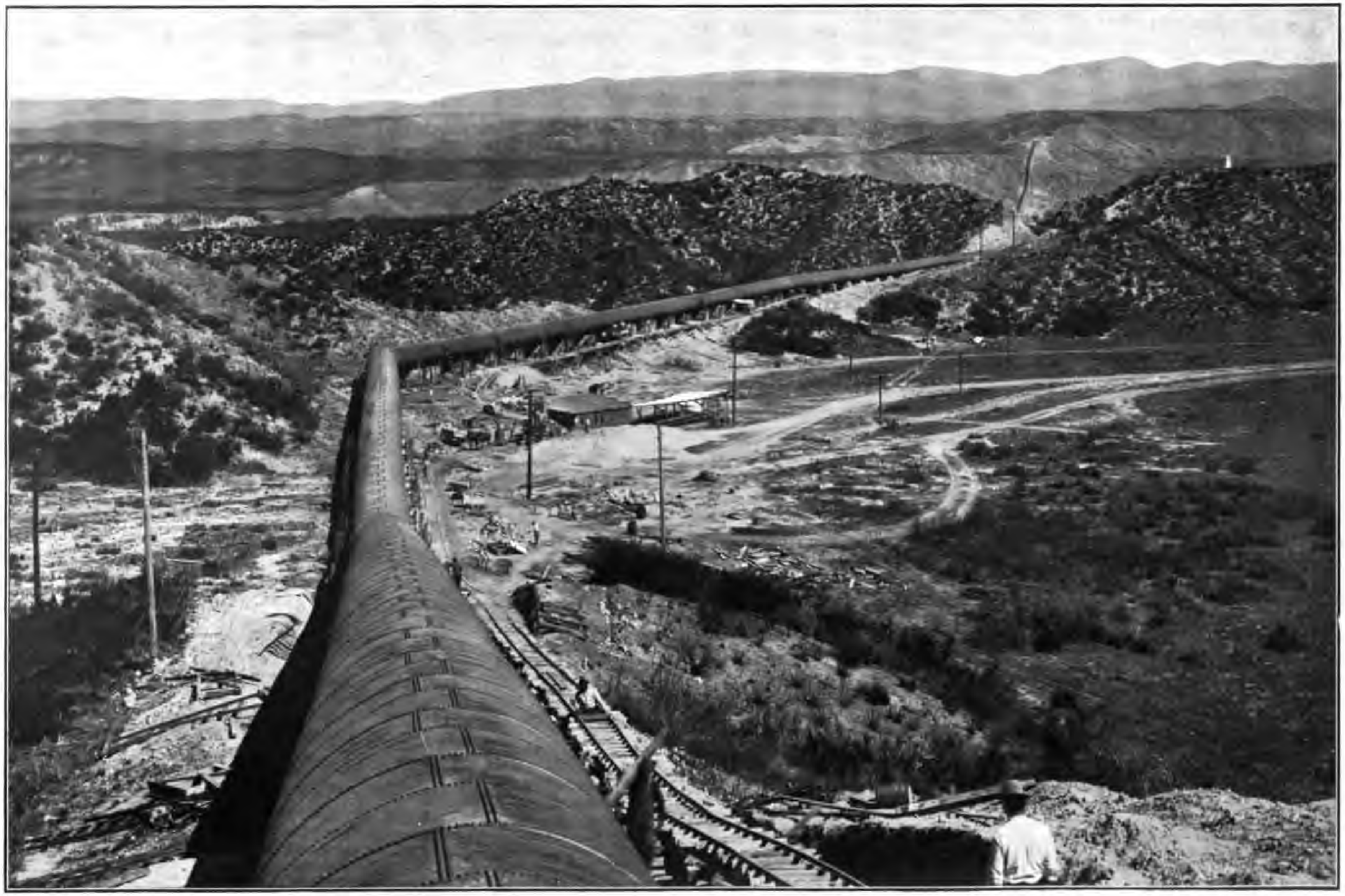
Reinforcement

The steel rods were placed ⅓ inch from the outside edge of the pipe. They were lapped 18 inches and wired together. After the wet concrete was cast around these steel rods, the steel was put under compression by the shrinkage of the concrete in setting. When the load came on, it was changed from compression into tension, and it was expected that there would be enough movement in this process to produce slight horizontal ruptures in the concrete. No such ruptures, however, were found in any of the pipes, as had been the case with other large concrete pipes made with thin shells, where spouting jets of water occurred along longitudinal cracks. For these reasons it is believed that the 9-inch shell of concrete is itself carrying the load and that the steel has not been placed in tension. The concrete pipes have all been buried in trenches and covered with soil. Where possible, these trenches were excavated with steam shovels, as in the Antelope Valley siphon. It is good practice to so bury the pipe in order to protect it against drying out and temperature movements. Concrete pipe should, where possible, be built in cool weather, so that it may be put under a condition of compression due to subsequent temperature changes, as concrete is about 10 times as strong under compression as under tension. Care was exercised in keeping the pipes moist by wetting down the backfilled ground and keeping it moist during the curing of the pipe. During this period the ends of the pipe were kept closed with curtains in order to maintain a humid atmosphere in the pipe. As soon as the pipe attained a sufficient age, as from a month to six weeks, it was slowly filled with water and kept full. In one pipe a circular crack opened at the bottom of the siphon. A leak of 6 to 8 gallons per minute developed before the pipe was completely filled with water. Instead of drawing off the water from the pipe, it was allowed to stand full for a week or ten days. The crack entirely closed with the swelling of the concrete, and no further trouble was experienced with it.

In the case of the Elsmere siphon, a leak of about 5 gallons a minute came from near the bottom of the pipe. The pipe was emptied, and it was found that there was a defect in the concrete. This was cut out and plugged with a small amount of new concrete, and the leak was stopped at little expense.

Expansion Joints

The first concrete pipes filled with water were in the Whitney and Elsmere canyons. These pipes have heads of 20 and 75 feet respectively. Two expansion joints were put in each of these pipes. They were of the "Z" type, and the joints were filled with asphalt. Slight leaks occurred at these joints, and no movements could be observed due to expansion or contraction. It was thereafter concluded that the expansion joints were unnec-



SOUTHERN END OF SOLEDAD SIPHON, 11 FEET DIAMETER, 8060 FEET LONG

essary, and none of the other concrete pipes had any expansion joints in them. Practically no trouble was experienced with any of the concrete pipes that were filled with water soon after their construction.

The Antelope Valley siphon crosses a valley with a total length of 22,746 feet. This valley has gently sloping sides. The north end, for a distance of 2,736 feet, is a concrete pipe which has a maximum head of 75 feet. It is here connected with a steel pipe, which has a maximum head of 200 feet. At the south end there is 2,314 feet of concrete pipe, with a maximum head of 75 feet. Because of the unavoidable schedule of the work, this concrete pipe was built first and the intervening steel pipe was not constructed for a year afterwards. It was not possible, therefore, to promptly fill the concrete pipe, and there was a scarcity of local water to adequately keep the ground over the concrete thoroughly soaked. Curtains were hung over the ends of the concrete pipe. The pipe unfortunately was built during the summer time instead of during cool weather. It was, therefore, subjected to a double shrinkage, due to temperature when cool weather did arrive and to drying out. This is an intensely arid region, with a relative humidity of about 20, and the summer temperatures exceed 100 degrees Fahrenheit. Six months after the concrete pipe was completed, a number of cracks opened in the concrete. These cracks ranged all the way from hair lines to openings as great as ⅛ of an inch. They occurred at intervals of 40 or 50 feet in some places, and in all aggregated perhaps 50 cracks. The superintendent who built the pipe was much disturbed over these cracks, and began cutting into the pipe dove-tailed openings about 1 inch deep, ½ of an inch wide at the inner surface of the pipe, and about ¾ of an inch wide at the base of the cut. These were then plugged with a cement mortar. After a few of them had been so plugged, the work was stopped, as it was considered undesirable to cut into the shell of the pipe and because it was believed that the pipe would expand and close the cracks when it was filled with water. After the steel pipe was laid and connected with the concrete, the pipe was slowly filled, the local water supply being limited and the leakage being as great as the inflow for several months. As the various sections of the Aqueduct became connected up, more water was available, and the pipe was at last filled, after it was over a year old. Quite a large number of leaks of considerable size, sufficient to make small boiling springs along the pipe, at first were developed. They perceptibly became less as the pipe soaked up, and within a month after the pipe had been filled it was entirely tight. A head of water was also accumulated at the upper end of the siphon by building a dirt dam in the pipe, and then suddenly the dam was broken and the mud and silt sluiced through the pipe and out the lower end. This may have facilitated the closing of the opening.

No longitudinal cracks ever opened in any of these pipes. Longitudinal cracks of this nature do not close with expansion of the concrete as in the case of the circular cracks. On other works, where these longitudinal cracks occur, the method adopted for closing them is to keep the full head on the pipe, drive thin steel wedges into the crack so as to hold it apart, then take the water out of the pipe, so that the crack can be grouted both inside and out, allow the cement to harden and then refill the pipe.

Transition Joints

The casting of a concrete joint, connecting a steel pipe with a concrete pipe under 75 feet ot pressure, is not entirely a satisfactory practice. In the case of the Deadman siphon, a 10-foot concrete pipe is connected with an 11-foot steel pipe at a point where the pressure head is 70 feet. An expansion joint was made at this connection, the concrete overlapping the steel for 6 feet, or the width of one plate, and the annular opening of ¾ of an inch between the steel and concrete caulked with oakum. It was difficult to make this opening tight. Threaded steel rods were cast in the concrete so as to project about 6 inches; a circular piece of angle iron was then fitted over the steel and holes bored in it to fit the threaded rods. The annular opening between the steel and the con-

crete was then caulked with oakum and the steel angle drawn down against the oakum with nuts. It was observed that this joint was tight, as the pipe filled up, until there was about 30 feet of head on the joint. It then gradually leaked more and more until a head of 70 feet was on the pipe, when the leakage amounted to about 10 gallons per minute. Apparently the steel pipe changed its form with the increased head and so caused the leakage. By a repeated recaulking under pressure, the leak was finally eliminated.

Similar joints were at first cast between the steel and the concrete on the Antelope Valley siphon, but after the experience on the Deadman siphon it was decided to make a rigid connection between the concrete and steel, and this was done by first riveting angle irons to the steel pipe and then casting a large block of concrete so as to envelope the steel pipe. This rigid joint proved satisfactory.

The cost of concrete pipes was found to vary greatly with the location in which they were built, and with the men who did the work. A pipe in a canyon with steep sides, with a length of 349 feet, where the forms and equipment were new to the crew, cost $42.48 per foot. This was the first pipe that this crew built. The second pipe, which is 411 feet long, also with moderately steep slopes, was built by the same crew at a cost of $28.00 per foot. The Antelope Valley pipe on the south end, built by another crew more familiar with this class of work, under conditions that were more favorable, cost $17.20 per foot. The cost of sand, rock and cement did not vary materially in these three pipes. These are field construction costs.

The Whitney siphon (No. 20) on the Saugus division was 955 feet long and of the same size and thickness; that is, 10 feet in diameter and a 9-inch shell. This was laid in a canyon, the sides of which had slopes of about 3 feet horizontal to 1 foot vertical, and the excavation was done by hand on the side-hill and by teams across the flat.

The following are the costs:

Excavation	$ 5.48	per foot
Concrete pipe	8.33	per foot
Steel	3.83	per foot
Backfill	2.64	per foot
Anchorages	.14	per foot
Blow-off	1.29	per foot
Engineering	.13	per foot
Total	$21.84	per foot

The concrete costs were not segregated in the detailed classification. The form costs are included in the pipe, and in this instance the forms were made of wood and cost $1.20 per foot. Mixing and placing concrete cost $2.88 per cubic yard, and the placing of the steel cost 83 cents per foot. Cement cost $1.65 per barrel on the works. The gravel costs were about 90 cents per cubic yard.

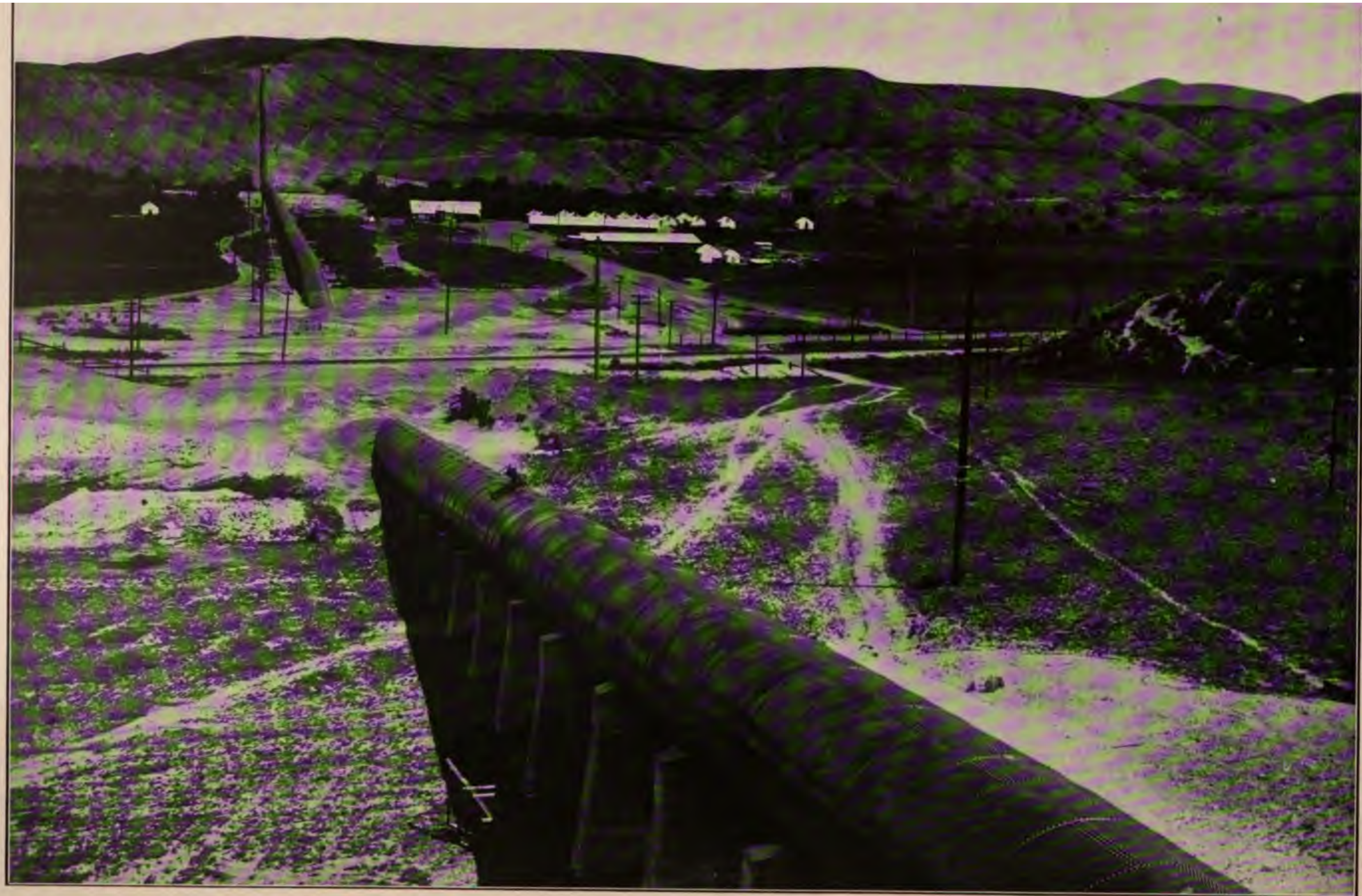
All the concrete pipes are 10 feet in diameter, have a 9-inch shell and rest on a concrete base.

Leakage

In the case of the Whitney siphon, when the pipe was filled, the leakage was at the rate of about 4,000 gallons per day. The expansion joints were then cut out and plugged with cement. Three months afterwards the leakage had dropped 320 gallons per day. This measurement was made volumetrically, as no water was admitted to the pipe during the test. The heads ranged from 60 to 70 feet.

An interesting comparison is made with the San Antonio steel siphon, which is constructed of ¼-inch steel plate, and was laid in hot weather. The pipe expanded and contracted considerably during its construction. The pipe was caulked and no seepage was shown on the surface of the ground. The length of this pipe is 695 feet, or 73 per cent. of the length of the Whitney concrete pipe. Its diameter is 9 feet and the maximum head 72 feet. On September 27th, 1910, this pipe was leaking at the rate of 4,577 gallons per 24 hours; on October 1st, 3,235 gallons; on October 9th, 2,400 gallons, and on November 27th it was practically tight.

An experienced concrete pipe man was employed on the construction of most of the pipes and was paid $250.00 per month; the shift boss



SOLEDAD SIPHON CROSSING SOUTHERN PACIFIC RAILROAD

METHOD OF HAULING PIPE SECTIONS TO POSITION

under him was paid $4.00 per day, and the labor $2.50 per day.

Jawbone Siphon

The Jawbone siphon, although not the longest, or the greatest in diameter, operates under the greatest head. It is located near the center of the Jawbone division, 120 miles from Los Angeles. It is 7,096 feet long, and operates under a maximum pressure of 365 pounds per square inch, or a head of 850 feet from the hydraulic gradient. The country is desert, and the canyon sides slope as much as 35 degrees. In locating the Aqueduct, 26 feet of grade were allowed for friction head on this siphon. The problem in designing the pipe was to attain, with a fixed grade, the smallest weight of metal consistent with safety. Theoretically the most economical pipe in this instance would be a tapering one, the large diameter at the top, where there is no pressure, and the small diameter at the bottom. In practice this ideal condition cannot be realized, but it can be approached by using a large diameter pipe, reducing it in several places as the pipe goes down the hill, and correspondingly increasing the size as it goes up the other side. The location of the stations along the pipe at which these changes in diameter are made, is the controlling element in the design and location. Clearly an indefinite number of combinations of lengths of different diameters can be made, one of which will give a minimum weight to the entire siphon. A graphical solution of this problem was made by a method evolved by Mr. E. A. Bayley, formerly locating engineer of the Aqueduct and at present Assistant Engineer for the Department of Public Service, City of Los Angeles. The pipe was built in accordance with the results obtained from this study. The diameters ranged from 10 feet at the ends to 7 feet 6 inches in the center, and the thickness of plates from ¼ inch to 1⅛ inches. The resulting saving in weight over a pipe of constant diameter consuming the same head was 298.4 tons, or 10 per cent. In a constant diameter pipe, the greatest thickness would have been 1¼ inches. The greater ease in working the thinner metal in the compound pipe is a material advantage.

Work was begun in January, 1912, and was completed in March, 1913. The pipe was laid on concrete piers, which are two feet thick and extend one-quarter of the lower circumference of the pipe. In breadth they are three feet greater than the diameter of the pipe. The piers are spaced 36 feet center to center across the bottom of the canyon, and closer for the thinner plates. They are built on bed rock on the hillsides, and in the bottom of the canyon are carried down about 8 feet into gravel. Erection of the steel started in the bottom of the canyon with the 1⅛-inch plate, and the pipe was extended up both sides simultaneously. The steel was placed in position on the hillsides by a broad gauge rope haulage way, constructed alongside the pipe and operated by a 15-ton hoist, driven by electric motors. The steel was shipped to Cinco, 4 miles from the siphon, and hauling was done by mules over sandy roads with an average up-grade to the siphon of 1.65 per cent. and short stretches with a maximum grade of 5 per cent. The 1⅛-inch 7½-foot diameter pipe across the bottom of the canyon was shipped riveted together in 5-ring sections 36 feet long, weighing 26 tons. These sections had to be hauled on trucks with special steel wheels having 24-inch tires. The team consisted of 52 animals, 6 abreast at the wheel, 3 freighters and 2 "swampers." The loading and hauling cost for these large sections was $3.21 per foot of siphon, or 24 cents per cwt.

Field Riveting

The field riveting of these heavy plates is of interest, as the rivets were 1¼ inch in diameter and each rivet weighed about 5 pounds. They were driven with the Thor and Boyer No. 90 air hammers, using air at 115 pounds pressure, operated by an Ingersoll-Rand compressor, "Imperial" type 10, driven by a 100-horsepower motor. A No. 60 Boyer hammer was used on the end of the air bucker inside of the pipe. The energy cost 1.7 cents per kilowatt hour. During the month of May, 1912, 1,160 rivets, 1¼ inches in diameter were driven at a cost of 27 cents each.

The detail unit costs, up to January 31, 1913, are given below. All of the steel had been placed at this time, and the work in February and March consisted chiefly of caulking and painting.

Excavation, 163 piers, $23.41 each, $ .50 per cu. yd.
Concrete, 187 piers, 59.08 each, 8.57 per cu. yd.
Forms, 187 piers, 3.79 each, 0.55 per cu. yd.
Average cost per pier, $86.28 = $9.12 per cu. yd.
Average cost per foot of siphon for trenching, 65 cents.
Average cost per foot of siphon for piers and trench excavation, 7096 feet, $2.83.
Pipe:

Steel at Cinco	—7096 ft. at	$21.80 per ft.—	$2.57 cwt.
Unloading & Hlg.	—7096 ft. at	1.42 per ft.—	.17 cwt.
Placing	—7096 ft. at	2.45 per ft.—	.23 cwt.
Riveting	—7096 ft. at	2.52 per ft.—	.30 cwt.
Caulking	—4109 ft. at	.90 per ft.—	.11 cwt.
Painting	—2546 ft. at	.65 per ft.—	.08 cwt.
Equipment	—7096 ft. at	3.66 per ft.—	.43 cwt.
Superintendence		.37 per ft.—	.04 cwt.
Engineering		.17 per ft.—	.02 cwt.
Blow-off proportion		.06	
Average cost		$34.00 per ft.—	$3.95 cwt.

These are field construction costs only and do not include auxiliary expenses for roads, water and minor details.

The equipment charge is subject to salvage credit.

There were 191,785 rivets driven, ranging in diameter from ⅝ inch to 1¼ inches, at an average cost of 8.8 cents.

The riveting crew consisted of four men, a riveter at $4.00 per day, a heater at $3.00 per day, a bucker at $2.75 per day, and a sticker at $2.50 per day; the names being descriptive of their respective duties.

The blow-off consists of three 14-inch valves, tested to 750 pounds working pressure and located in the lowest part of the siphon.

Asphalt Paint

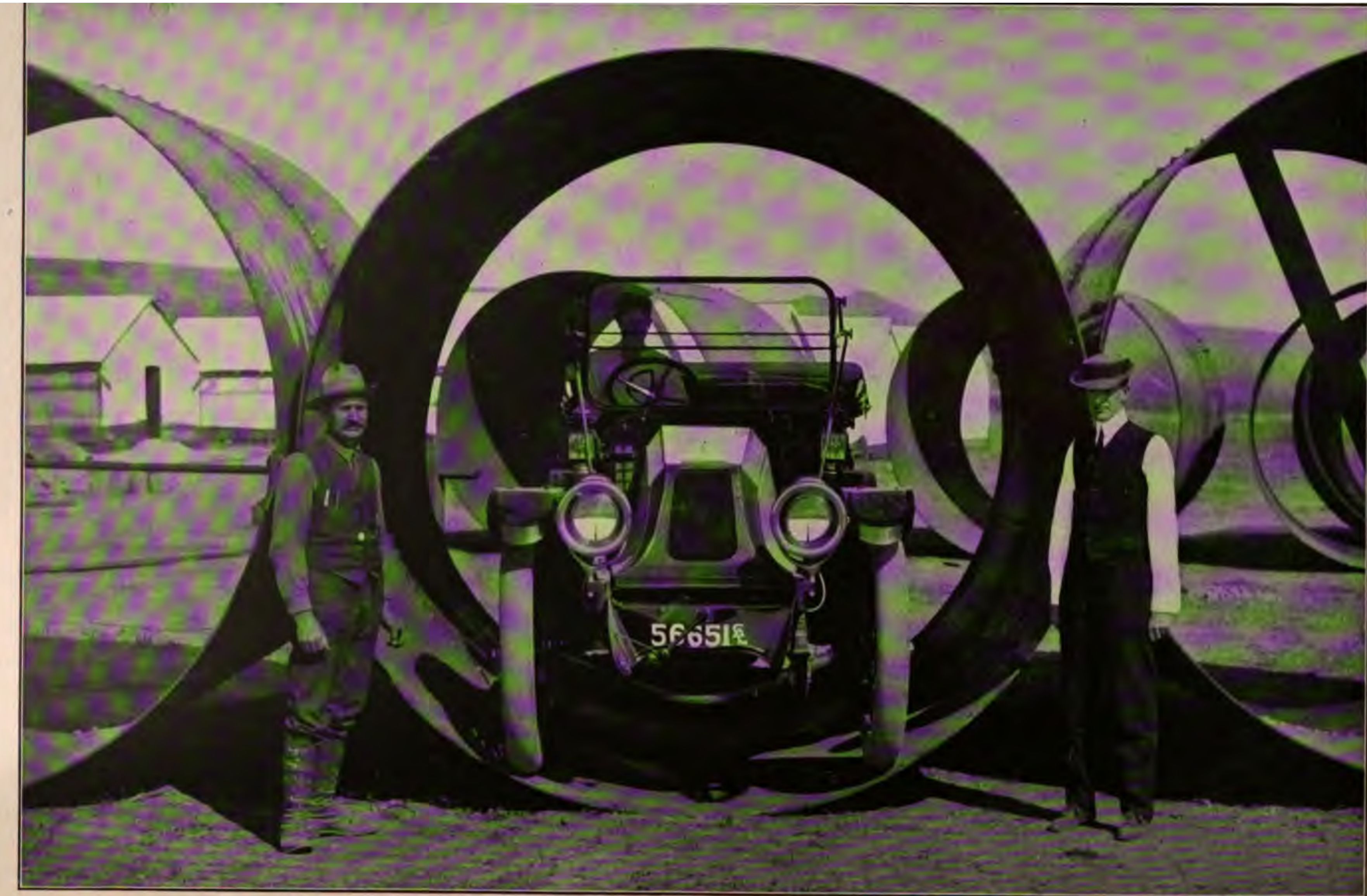
The paint used on the pipe was a residual hydro-carbon oil, resulting from the manufacture of gas from California asphalt oil, which penetrates rust and rust scales on the metal. All the steel work on the Aqueduct is painted with this material. Its cheapness is an advantage, as it costs but $4.00 per barrel of 50 gallons. One gallon of the paint used will cover about 400 square feet with one coat. The cost of painting with two coats varies from ¼ cent per square foot under the most favorable conditions, to 1¼ cents under the most unfavorable conditions.

There was movement in the pipe during construction, due to expansion and contraction, but this stopped when the pipe was filled with water and the transitions built. No expansion joints are used in any portion of the siphon.

Antelope Valley Siphon

This siphon, while not the largest on the Aqueduct as to diameter or pressure head, is the longest and has the greatest tonnage. It is 10 feet in diameter and 4.11 miles in length, with a maximum head of 200 feet. The siphon consists of 15,597 feet of steel in the center and 6,197 feet of concrete at the two ends, extending into the gently sloping valley until a pressure head of 80 feet is reached. The steel consists of 7,249 feet of ¼-inch plate, 3,698 feet of 5/16-inch plate and 4,650 feet of ⅜-inch plate. The construction of the concrete pipe was commenced in July, 1911, and completed in November of the same year. All steel and supplies had to be brought from a railroad station 35 miles distant. The concrete was built entirely with Fairmont tufa cement. The average haul for the cement was 22 miles and cost about 12 cents per ton mile. An average progress of 50 feet per day was made in the construction. The forms were stripped on the third or fourth day, at which time the trench was backfilled. The inside of the pipe was plastered about ¼ inch thick with a 1 to 2 mortar.

The costs for both portions of the concrete pipe for the straight field construction charges are given below:



PIPE SECTIONS FOR SOLEDAD SIPHON

COSTS OF CONCRETE PIPE—ANTELOPE VALLEY SIPHON

Description	North End Progress	North End Unit Cost per foot	South End Progress	South End Unit Cost per foot
Steam Shovel Excavation	2750 ft.	$0.59	3447 ft.	$0.94
Excav.—Moving Shovel	2750	.05	3447	......
Lining—Rock and Gravel	2750	1.85	3447	3.68
Lining—Cement	2750	6.25	3447	5.80
Lining—Mixing and Placing	2750	.96	3447	.91
Lining—Setting Forms	2750	.55	3447	.62
Lining—Steel and Placing	2750	4.00	3447	4.30
Plastering	2750	.70	3447	.26
Superintendence	2750	.17	3447	.26
Backfilling	2750	.33	3447	.39
Engineering	2750	.03	3447	.04
Average cost per foot of completed section		$15.48		$17.20

An average of 1.48 cubic yard of concrete per lineal foot were placed on the north end and 1.3 cubic yards on the south end. These costs do not include over-head or auxiliary expenses, such as equipment, roads and trails, water supply, etc. These charges amount to about 20 per cent. additional.

The steel pipe for this siphon was furnished, rolled and punched, by the Riter-Conley Manufacturing Company at a cost of $1.50 per cwt. f. o. b. factory at Leetsdale, Penn. It was shipped nested, and the railroad freight to Mojave amounted to 80 cents per cwt. The haul from Mojave to the siphon was 35 miles. Twelve-animal teams were used in this haul, the average load being 12.9 tons, or a little more than a ton to the animal. A team made 20 miles a day, with a load, and took three days for the round trip. The cost for this long haul averaged 12 cents per ton-mile.

The pipe was laid on the ground in a shallow trench, the excavation being done by teams, and the pipe backfilled to about one-third its diameter. The plates are 72 inches wide and all field riveted. The ¼-inch and 5/16-inch plates were riveted alongside the trench in four-ring sections, 24 feet in length, and the ⅜-inch plates in two-ring sections, 12 feet long. These sections were then rolled into the trench and picked up with an "A" frame derrick, fitted in place and bolted. The sections were largely riveted together during the evening or at night, the heat during the day making it uncomfortable to work inside the pipe. The construction of the steel was started in the center and extended both ways. The riveting crews made good progress on this work, due largely to the bonus system adopted. The Aqueduct record for field driven rivets was made in the erection of this pipe, one shift driving 1,650 ⅝-inch rivets in eight hours.

The compressor plant was located at the center of the siphon. The City's electric transmission line did not extend south of Mojave, and it was necessary to provide other than electric energy for power. Four 40-horsepower Aurora gas engines were salvaged from traction engines that had been used on the Mojave division, and these were all belted to a line shaft and the shaft in turn belted directly to an Ingersoll-Rand Imperial type air compressor. The layout was economical and satisfactory. Two lines of 4-inch O. D. casing delivered air at a pressure of 110 pounds. No. 90 Boyer and Imperial air hammers were used in riveting. The pipe was caulked outside only. The 24-inch blow-off valves were located at the lowest point in the valley. These valves are placed on the horizontal diameter of the pipe. The pipe is painted both inside and out with two coats of tar paint.

The following table gives the direct field charges for the steel pipe:

COSTS OF STEEL PIPE ON ANTELOPE VALLEY SIPHON

Description	Length Feet	Unit Cost	Cost Cwt.
Trench Excavation	15,597	$ .33	
Anchorages—proportion	"	.48	
STEEL PIPE			
Cost rolled and Punched at Mojave	"	9.84	$2.30
Loading and hauling	"	1.46	.34
Placing	"	.52	.12
Riveting	"	1.19	.28
Caulking	"	.24	.06
Painting	"	.15	.04
Equipment	"	.87	.21
Superintendence	"	.11	.03
Engineering	"	.04	.01
Backfill	"	.19	
Bell hole—proportion	"	.11	
Dismantling camp—proportion	"	.01	
Manholes—proportion	"	.01	
Blow-off valves—proportion	"	.03	
Average cost per foot complete except transition		$15.58	$3.39

To the above cost should be added 10 per cent. for over-head and auxiliary charges. The average cost of driving 645,957 rivets was 2.9 cents per rivet, and the average cost per pound erected is 3.39 cents. Considering that the work was built 35 miles from a railroad in a desert region, the cost was remarkably low.

The erection of steel commenced in April and was completed in September, 1912. The greatest progress was made during the month of August, when 5,940 feet were erected.

Expansion

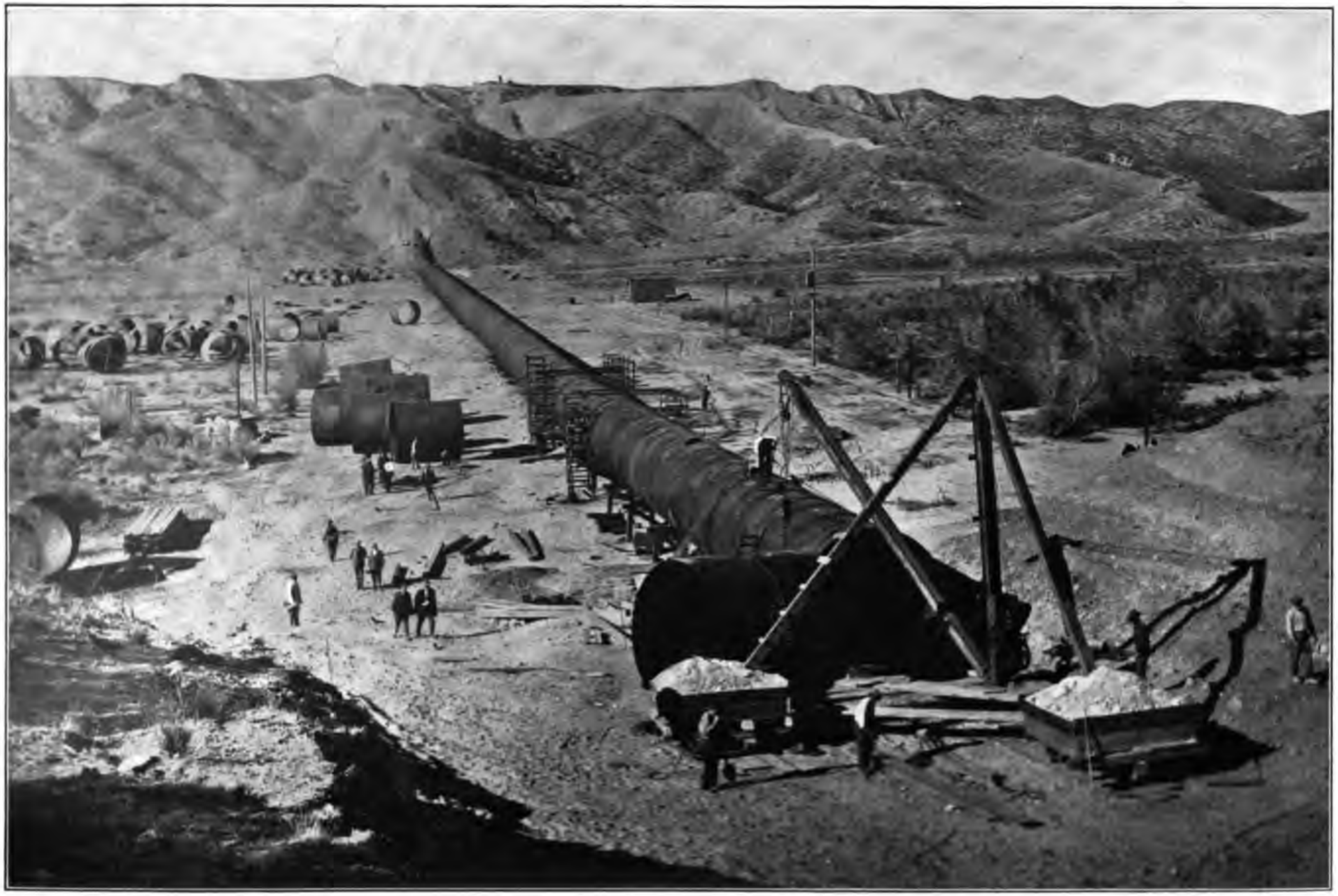
Expansion in this pipe was observed as 23 inches from 5:00 o'clock in the morning, the coolest part of the day, until mid-day. As soon as the pipe was filled with water this movement ceased, because the temperature of the pipe is held more uniform and also the weight of water tends to prevent it. There are no expansion joints.

The steel pipe at the points of transition extends 5 feet into the concrete pipe. The pipe was filled with water up to this point, and, during the cool weather, mass concrete block anchorages were built, encasing the steel pipe for a length of 27 feet. At a distance of 6 feet apart, or at the center of each of the three plates imbedded in the concrete, angle irons, cut in 4 segments, were riveted to the outside of the pipe. The concrete was put in to a depth of 10 feet beneath the pipe with a width of 15 feet, and a thickness of 1½ feet around the top of the pipe. Reinforcing bars ¾ inch in diameter were used in the bulkheads, transverse rods being spaced 4 inches apart, and 34 longitudinal rods spaced about 2 feet center to center and staggered.

The pipe was filled with water for several months and tested. At the points of transition a hair crack occurred, where the new concrete bulkhead was cast against the old concrete pipe. This caused a small leak, which was stopped by forcing grout into the joint with a sewer trench pump. There are 150 cubic yards of concrete in the two transition anchorages, which cost $2,223.00.

Notes on the Location of Large Pipe Lines

The experience with reference to location of large pipe lines, at least those built on top of the ground, is that horizontal angles should be avoided as much as possible, and that they should not be large, on account of expansion. In the 10 miles of steel pipe on the Aqueduct there has been no trouble with buckling, when the pipe was empty, except at the angles. At a horizontal angle on the north end of the Jawbone siphon, during its construction, the pipe buckled so as to be depressed as much as a foot from a true circle, but when it was filled with water, this buckle, as in other cases, was entirely rounded out. The head at this point was approximately 100 feet. The pipe at this point was made of ¼-inch plate. At the south end of the Soledad siphon a buckle occurred at a horizontal angle before the pipe was filled, which did not completely come out with the filling. The head at this point is about 40 feet, the diameter of the pipe is 11 feet, and the thickness of the plate ¼ inch. The plate was depressed from 3 to 4 inches at this point, and this was the only deformation on the entire line. It is not serious. The horizontal and



NORTH END OF SOLEDAD SIPHON, SHOWING METHOD OF PLACING STEEL PLATES

vertical angles in the pipe should be combined where possible. It requires more detailed care in making up the cuts of the plates, but it is feasible to do this, and it was done in a number of instances on the Los Angeles Aqueduct.

Pressure Tunnels

All of the siphons on the Aqueduct were built either of steel or reinforced concrete, with the exception of the one at Sand Canyon, which originally was a combination of two incline pressure tunnels, connected with a steel pipe across the narrow bottom of the gorge. Two other canyons were examined with the view of building pressure tunnels instead of steel pipes, but this class of construction was rejected there because the rock did not appear to be of sufficient strength and homogeneity.

Jawbone Canyon Test

At the Jawbone Canyon a test tunnel was driven, the finished diameter of which was 9 feet 3 inches. The total length of the tunnel was 305 feet, and a concrete bulkhead, 6 feet thick, was built 203 feet from the portal.

The concrete lining of the tunnel was 10 inches in thickness and was made with natural gravel, 30 to 40 per cent. remaining on a ¼-inch screen. Straight Monolith cement was used, with a mix of 1 to 4, and 10 per cent. of lime, as compared to the cement. It was plastered with a 1 to 2 mortar, with 20 per cent. of lime. The rock formation is a porphyry, not hard, and rather shattered, with a few clay seams and lines of fracture, resulting in smooth slip lines. The tunnel had 150 feet of rock cover over the bulkhead and 225 feet over the face. The tunnel was filled with water and subjected to pressure under a theoretical head of 1,100 feet.

Lines of rupture developed and demonstrated that the rock in this canyon was not of suitable character for a pressure tunnel.

Sand Canyon

In the case of Sand Canyon, however, the rock on the surface was a hard gray granite, massive in appearance and offering conditions which seemed to be satisfactory. The rock encountered was as hard as any in the entire 53 miles of tunnels on the Aqueduct. It required from 40 to 50 pounds of 40 and 60 per cent. gelatine dynamite per foot to excavate the section. Occasional seams occurred in the rock, so that when it broke it left faces that were smooth, but these were rare as compared to other tunnels.

Estimates were made of the relative cost of building a steel siphon, as compared to a combination pressure tunnel and steel pipe, which indicated that the pressure tunnel would be the cheaper. This, however, was not justified by the actual cost of the tunnel work, which proved to be more expensive than a steel pipe would have been.

The maximum head on this siphon is 455 feet. The pressure tunnel was built 9 feet in the clear and circular. The steel pipe connecting the two pressure tunnels was 8 feet 6 inches in the clear, and built of plates 11/16 of an inch in thickness. On the north side, the incline connected with a covered conduit and on the south side with a tunnel. The length of the north incline was 638.25 feet and the one on the south side 631.37 feet. The horizontal length between the inclines was 1,517 feet. The total length of the structure was 2,787 feet. The friction and entry heads allowed were 6.17 feet. The length of 8-foot, 6-inch steel pipe was 889.9 feet. The pipe was carried to the foot of the incline at the south end and into the horizontal section of the tunnel on the north side 300 feet. The covering over the north end of the pipe was 83 feet and over the south end of the pipe 170 feet. The portal of the horizontal tunnel, at the north side of the canyon, was in hard, massive granite. On the south side of the canyon it was in rock, but not of so sound a character. Consequently the pipe was put under a greater covering at the south side than at the north side.

Concrete Lining

The tunnels were lined with concrete, which was approximately a foot in thickness, with a 1-2-4 mix, straight Portland cement being used. The concrete lining was carried forward ten feet over the ends of the pipe. Holes

were left in the concrete for grouting in all the horizontal portions of the tunnel, and for some 50 feet up the incline on the south side. Grout was forced into the grout holes with a triplex force pump, with pressures of over 200 pounds per square inch. The concrete was laid in the inclines from the bottom up. It was discharged through 8-inch pipe, behind the forms, from the head of the incline. The concrete, built up in this way, in horizontal sections, flowed into all the crevices and spaces in the rock. No grout, except as mentioned above, was pumped behind the concrete in these inclines, because of the very compact way in which it was delivered behind the forms.

Pressure Tests

After completion, this pipe was partially filled with water, and the pressures gradually rose to from 60 to 70 pounds, when they began to drop and fell to 50 pounds in a short time.

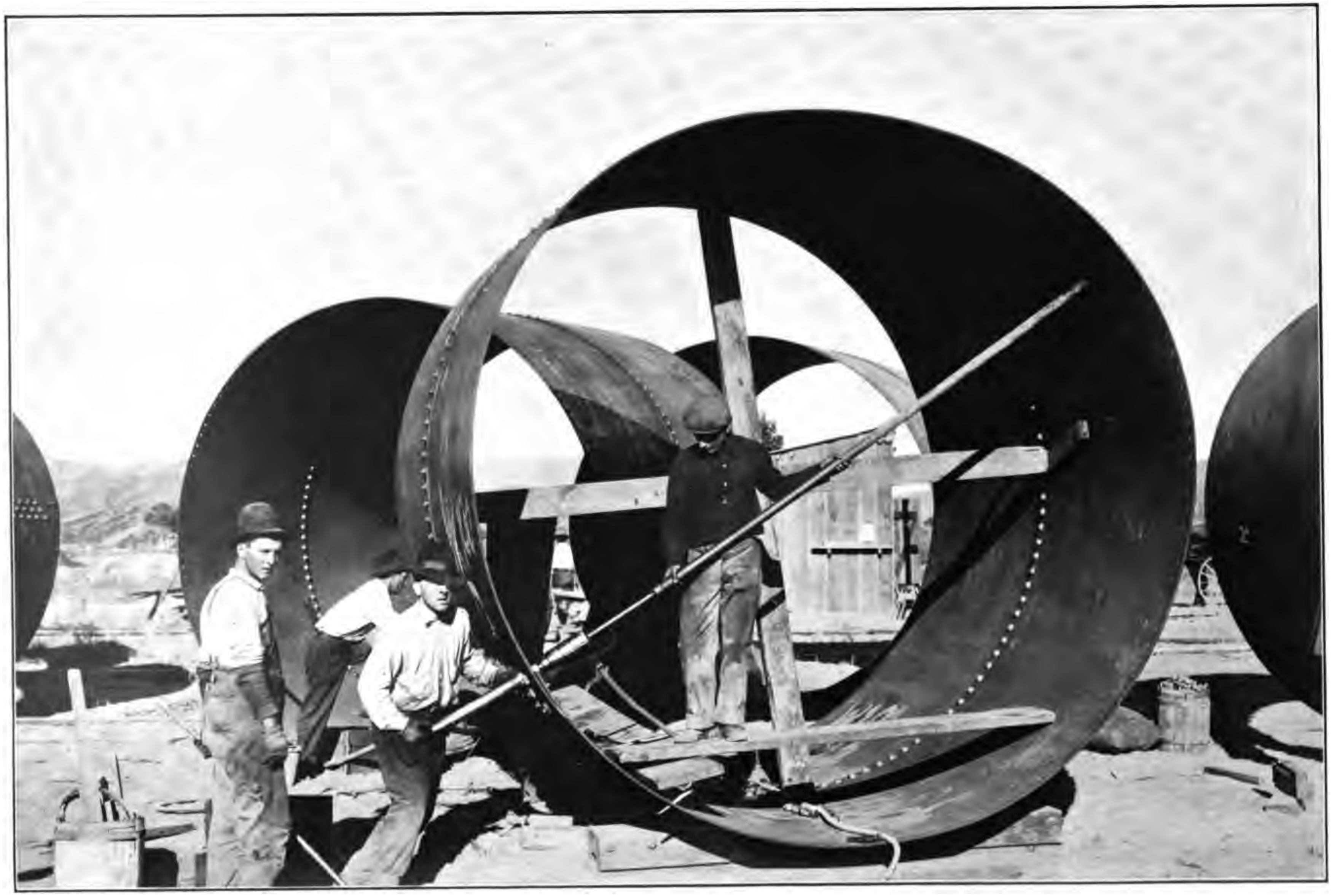
A spring developed on the north side of the canyon on approximately the level of the bottom of the pipe and flowed continuously. From 3/10 to 4/10 of a second foot of water was being turned into the pipe, when the head remained at 50 pounds. A slight leak developed through the rock into the tunnel on the north end, about 30 or 40 feet south of the bulkhead. There was also a small seep through the rock at the south end. No water passed through either bulkhead. On March 25th, 1913, the spring on the north side, about 150 feet down the canyon from the pipe, was flowing 1/10 of a second foot; the seep into the north tunnel .05 of a second foot, and the south tunnel .04 of a second foot, and other springs were appearing on the north side of the canyon from 200 to 300 feet from the pipe. The total apparent seepage amounted to about .122 of a second foot. At this time the pressure gauge showed 45 pounds on the steel pipe.

On the morning of March 26th, at 9:45 A. M., the pressure was 55 pounds on the gauge. The flow at the spring on the north side had slightly increased, but the seepage from the south side had remained the same. On March 26th, at 1:28 P. M., the pressure on the pipe was 60 pounds. The Aqueduct at this time having been completed above, about 100 second feet of water were turned into the pipe, the intention being that if there was a weakness in the structure, it should be developed to a failure promptly. At 1:30 P. M., the pressure was 100 pounds, and at 1:32 about 150 pounds. The gauge on the pipe was calibrated to read but to 160 pounds, and it is possible that the index hand stopped at 150 pounds. On account of the spring that had developed, sawdust and fine screened sand were put into the flowing water entering the siphon. No additional leak occurred on the south side at this time, but the spring east of the pipe on the north side of the canyon blew out at 1:33 P. M., and a large flow of water developed. At about 1:34 P. M. a break occurred on the side-hill, approximately 80 feet in elevation above the top of the pipe and about 150 feet west of the pipe. The blow-out was immediately opposite the north end of the steel. The pipe was not full enough of water to run out of the upper end of the south incline. The gauge showed a swing of about 10 pounds during the filling of the pipe. These two blow-outs on the north end discharged about 100 second feet of water.

Failure of Rock Tunnel

After the break, the large valves were opened, the inflowing water shut off and after the pipe was emptied, it was inspected on the inside. A large crack was found, about 3 inches in width, starting at the bottom of the steel on the north side and running diagonally up each side to the spring line, at a distance of about 50 feet from the end of the steel. The crack then followed the spring line, with an opening of about one inch in width, and with about ¾ of an inch offset, for 100 feet in length. The crack ceased 230 feet from the end of the steel, in the top of the tunnel. One hundred feet from the end of the steel on the north side, there was some spalling of the concrete in the roof. There was no indication of failure at the south end of the pipe. The end of the steel on the north side was 1½ inches higher than the concrete with which it formerly had con-

SIPHON CROSSING NO NAME CANYON ON CONCRETE PIERS



FIELD RIVETING OF PLATES FOR SIPHON PIPE

nected, and had been pushed out of the tunnel 1½ inches. There is a horizontal angle in the steel outside of the tunnel and this had been sprung outward, shearing off the tops of the concrete piers at the angle. The horizontal tunnels between the concrete bulkheads around the steel, and the portals, had not been lined with concrete, because of the hardness of the rock. A careful examination of the rock between the bulkhead and the portal on the north side of the canyòn was then made and two places were found where the rock was less hard than at other points, and at the inside one of these places the spring previously referred to had occurred.

A study of the ground subsequent to the failure indicates the possibility that at one time the bed of the canyon was further north than its present lowest point, and that this channel had subsequently been filled with debris, consisting largely of massive rock fragments, so that the solid rock covering over the tunnel was not as great as would be indicated by the profile, and that the granite portal, which is ledge rock in place, on the north side was misleading. The blow-outs on the surface occurred in a soft decomposed granitic rock that had some indication of stratification.

Attempt to Repair Damage

The City Water Department had on hand a large quantity of 66-inch steel pipe, ⅜ of an inch in thickness, and it was determined to extend the steel further under the mountain on the north side with this pipe, with the view of making a quick repair of the siphon and ultimately laying a larger pipe on the outside. This smaller pipe was extended into the tunnel on the north side for 345 feet, to a point where the covering over the pipe was 170 feet. The circular space between the 5½ and 8½-foot pipe was closed by being filled with moderately wet concrete to within about 4 inches of the top of the opening and this was allowed to set for a few hours in order to get rid of shrinkage. The remaining space was then rammed with a concrete that was just wet enough to ball in the hand. This connection held during the subsequent test.

Ten second feet of water was turned into the pipe on May 16th, 1913. A leak developed within half an hour on the south incline, two-thirds of the way up the south slope. The siphon had been completely filled, and water was running out of the south end. When the leak was observed, the water was turned off by Mr. Van Norman, who was the engineer making the test. The pipe was then emptied. While a small amount of water showed on the surface, no movement of the soil covering on the hillside had started. The examination on the inside of the pipe showed that for the first 100 feet down the incline from the top on the south side there were no cracks in the concrete; that below the 150 feet there were numerous small cracks, the largest being possibly ¼ of an inch in size, and many small irregular cracks. No cracks were found in the lower one-third of the incline.

Final Failure

It was decided that if the siphon were weak, it was important to have the failure at once, and a further test was made on May 18th. Twelve second feet of water was turned into the pipe at noon. Leaks quickly showed up about two-thirds of the way up the hill on the south side. Water flowed through the pipe and out of the south end. The leakage was largely absorbed by the rock and soil covering. Not over one or two second feet showed up on the surface during the 18th. Slipping of the soil and rock began about 1:00 P. M. One large slip occurred at 1:00 A. M. of the 19th, which shut off all the surface water for an hour and a half. Small streams again developed at 2:30 A. M. of the 19th. At 6:00 A. M. a flow of 42 second feet was turned into the siphon, and another large slip occurred which shut off all of the water for 10 minutes. This was followed by a great cutting of the hill on the south side. The water level had fallen rather an indefinite amount in the siphon, probably from 100 to 150 feet. The flow of 42 second feet was maintained for an hour to an hour and a half. About 250,000 cubic yards of material was displaced from the hill on the south side and moved from 30

to 50 feet. About 20,000 cubic yards reached the bed of the canyon.

The water was drawn off from the siphon about 7:00 A. M. on Tuesday, the 20th, and the pipe again inspected. The concrete was found to be badly cracked, the largest opening being two inches in width, 125 feet from the bottom on the south side. This was a slab twenty feet long and elliptical in shape in the top of the tunnel. The opening was two inches at the upper end and tight at the lower end. The concrete remained in line. On the north incline of the siphon a few small cracks were found near the top. The bulkheads both remained tight. No further leaks occurred on the north end.

While the granite is usually hard and massive, fissures occur at intervals, but those that were observed during the driving of the tunnel were so slight that it was not possible to insert the blade of a pen-knife in them and they were apparently filled with gouge, which possibly was the result of the grinding of the rock during some crustal movement. A careful examination of the canyon indicates that large blocks of rock which appear on the surface, and containing perhaps from 50 to 100 yards, are fragments broken from overhanging cliffs and are not in place, and that the solid rock covering over the tunnel on both sides of the canyon is less than would be indicated by the surface profile. However, the tunnels in the inclines were all in granite in place.

Concrete in setting has a slight shrinkage, and it is probable that this shrinkage gave sufficient space to permit of a slight cracking of the concrete when the high pressure went on. Concrete will seep somewhat freely under heads of 150 feet or more, even if it is a rich mixture and well placed. In either of these events enough water may have been passed through the concrete to have filled the crevices or fissures in the rock for an indefinite distance, and thus caused a hydrostatic pressure to be set up in the entire fissure, as well as in the inclined tunnel itself, and this pressure having been extended upwards to points near the surface of the ground, produced a rupture of the rock near the surface and succeeding ruptures to lower levels until the tunnel itself was reached, when the concrete could have broken and formed the large openings described. In any event the rock and tunnel were ruptured on these two different occasions, and it is believed that in the first rupture the overlying prism itself was lifted and set down again in a position that was different by two inches. This was the only failure on the entire 233 miles of the line.

Replaced with Steel

This pressure tunnel was replaced by an all-steel siphon, on a new location across the canyon. The 890 feet of 8½-foot steel pipe used in connection with the pressure tunnel was taken out, moved to the new location and formed a part of the new siphon.

STEEL SIPHON DATA

Costs for steel pipe in place. Excavation, piers and transition not included.

Name of Siphon	Length Ft.	Diam.	Plate Ins.	Head Ft.	Weight Tons	Mill Cost	Total Cost	Cost per cwt.
Nine Mile	1,415	9' 6"	¼-5/16	175	252.75	$ 9,400	$26,456	$5.63
No Name	2,016	9' 3"	¼-9/16	365	481.50	16,172	44,249	4.60
Sand Canyon	890	8' 6"	11/16	455	428.29	12,648	34,590	4.03
Grapevine	2,339	9' 3"	¼-9/16	355	651.16	19,231	52,926	4.07
Jawbone	8,095	10'-7' 6"	¼-1⅛	850	3216.51	95,005	265,065	4.10
Pine Canyon	3,841	9'	¼-¾	480	1508.51	44,547	110,130	3.66
Antelope	15,597	10'	¼-⅜	200	3511.63	103,712	231,902	3.30
Deadman	3,430	11'	¼-½	245	1071.07	35,977	80,150	3.75
Soledad	8,041	11' & 10'	¼-½	260	2274.47	76,395	172,151	3.80
Quigley	612	11'	¼	67	116.74	3,918	9,629	4.13
Placerita	1,572	11'	¼	105	313.72	10,537	27,097	4.30
*Dove Sp. and San Antonio	1,727	9'	¼	105 72	261.64	22,315	30,423	5.83
TOTALS	49,575				14,088		1,086,766	
Total Force Account	47,848				13,826.36	$427,542	$1,056,353	Av. 3.80

AVERAGES: Steel delivered, $2.70 per cwt.; erection .80 per cwt.; equipment, .30 per cwt. *Contract. City paid freight and haulage and supplied power and painted pipe.

PERMANENT HYDRO-ELECTRIC POWER DEVELOPMENT AN IMPORTANT FEATURE OF THE AQUEDUCT PROJECT

Preliminary Plans as Affecting Power

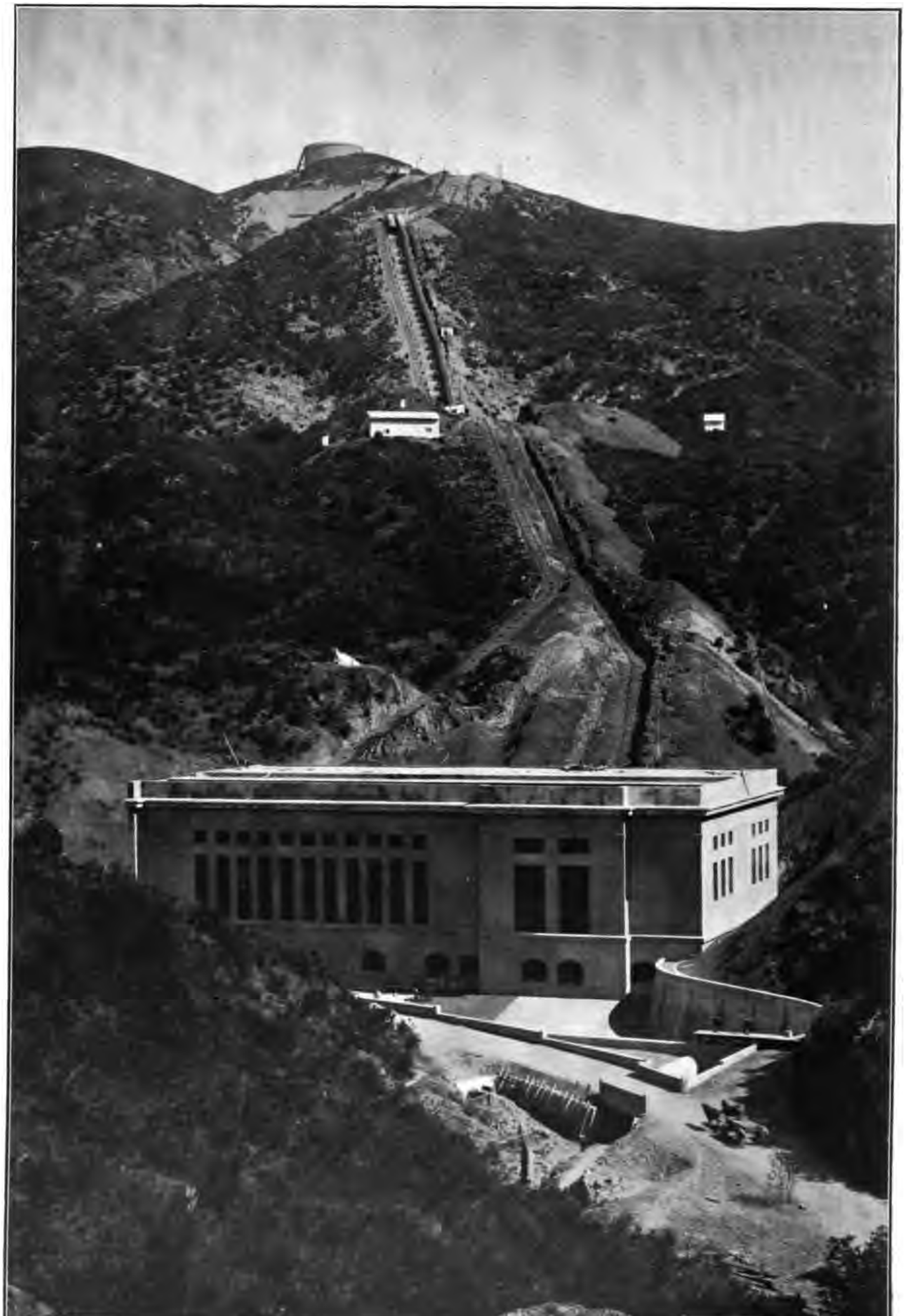
The opportunity for the development of large quantities of hydro-electric power along the line of the Aqueduct and on certain natural streams tributary to the Aqueduct water supply has at all times been contemplated as a feature of the City's Aqueduct project, destined to be of immense value as a reliable source of hydro-electric power, which may be developed and supplied at very low cost, thus assuring low rates to electric consumers and serving an important part in the encouragement of industry.

Opportunities for power development along the line of the Aqueduct itself result from differences of elevation in excess of that which is required as a gradient for producing and sustaining a gravity flow of the water in the Aqueduct. Such excess differences in elevation occur at four points along the Aqueduct, one just below the Haiwee reservoir, 162 miles from the City, where the difference in elevation equals approximately 190 feet; the second in the San Francisquito Canyon, 47 miles from the City, equalling approximately 940 feet; the third in the San Francisquito Canyon approximately 40 miles from the City, equalling approximately 530 feet; and the fourth between the end of the Aqueduct and the lower San Fernando reservoir, 25 miles from the City, equalling approximately 300 feet, or a total gross head of 1,960 feet available for power development, with an assured constant flow of water of between 400 and 430 second feet.

In addition to the power developed on Cottonwood and Division Creeks, in connection with the construction of the Aqueduct, the City has secured, in large part, and is seeking to secure in completion, further power opportunities on Cottonwood Creek and other creeks tributary to the Owens River, together with the opportunities for the development of power along the Owens River Gorge below the City's Long Valley reservoir site which, in conjunction with the Aqueduct power, fully developed, would be sufficient to deliver approximately 200,000 horsepower at the City, during the periods of peak demand of each day, at an average load factor of 55 per cent.; that is, an average throughout the day equal to 55 per cent. of the peak demand, which these sources of power would be sufficient to supply.

The providing of the Fairmont storage and regulating reservoir and the Dry Canyon regulating reservoir, above and below the two most important power sites along the Aqueduct, will not only assure the reliability of the power, but will also afford opportunity for the development of capacities sufficient to take care of peak demands approximately two and one-quarter times greater than the average. These storage and regulating reservoirs, together with the Haiwee reservoir, the Long Valley Reservoir and proposed reservoirs on the Cottonwood and other creeks above the proposed power plants, will thus not only provide assurance against any emergencies along the line of the Aqueduct affecting the power supply and against the shortage of water during dry periods, but also make possible variations in the flow of the water during the day so as to take care of peak loads without the necessity of providing for the great cost of installing and maintaining auxiliary steam plants, either for emergency use or for carrying peak loads.

The Aqueduct Consulting Board of Engineers, consisting of Messrs. Freeman, Stearns and Schuyler, in their report concerning the Aqueduct and the Power opportunities along the Aqueduct, summed up their references to the possible power developments in the following manner:

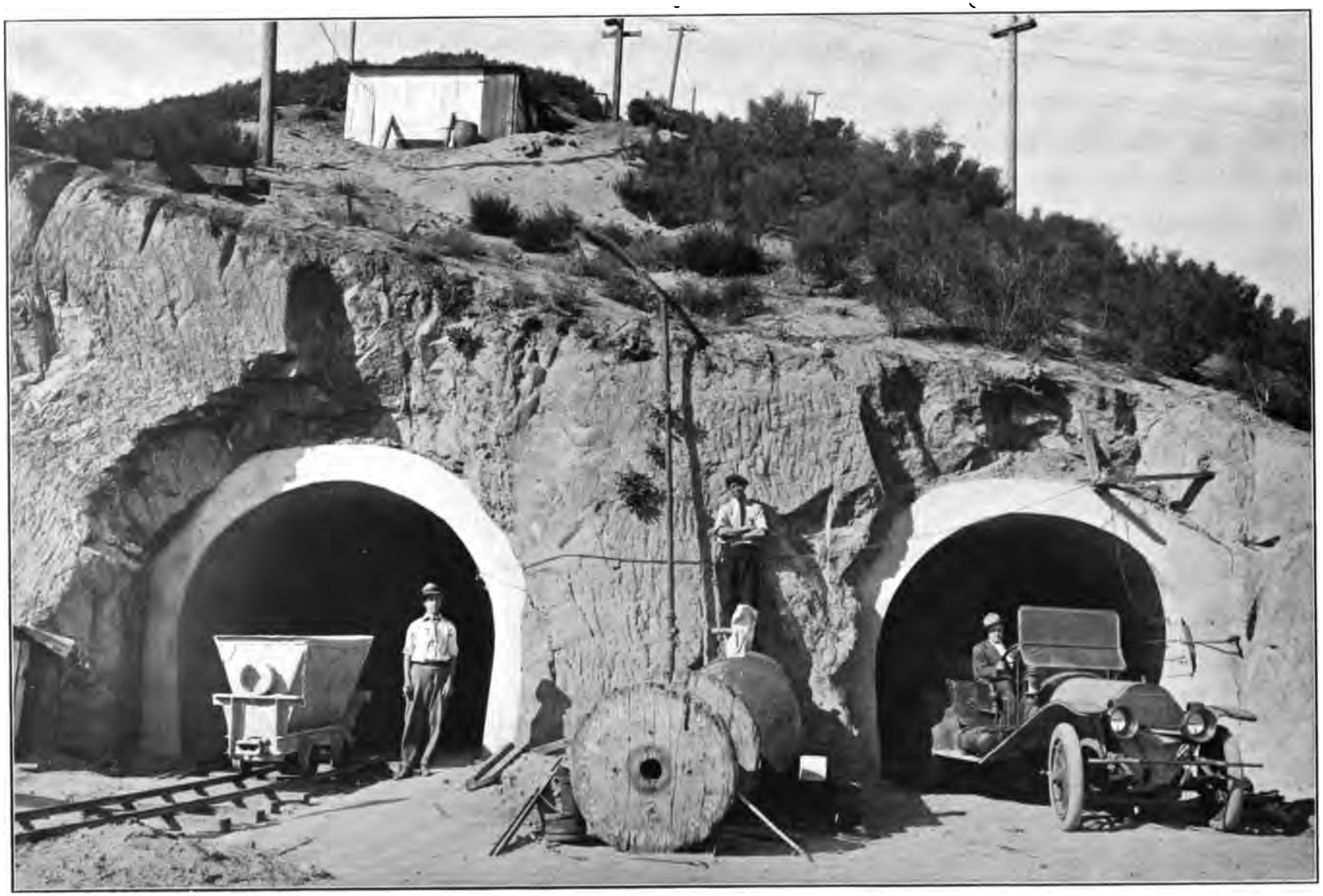


POWER PLANT NO. 1, SAN FRANCISQUITO CANYON

SITE OF POWER PLANT NO. 2, SAN FRANCISQUITO CANYON

SURGE CHAMBER OF POWER PLANT NO. 1, SAN FRANCISQUITO CANYON

PART OF PENSTOCK OF POWER PLANT NO. 1



SOUTH PORTALS OF PENSTOCK TUNNELS, POWER PLANT NO. 1

"The conditions for the economical development and maintenance of the power are very favorable and its safety against interruption or diminution by drouth, and the permanent character of the aqueduct, tend to make the power development feature particularly attractive and valuable."

Power Bureau Organized

Realizing the necessity for the determination and adoption of general plans to be followed in proposed power developments along the Aqueduct and on natural streams, in order that the location and construction of the Aqueduct might conform to the best advantage to such plans for power development, and in order that temporary works for by-passing the water of the Aqueduct might be avoided as far as practicable at the various power sites, and realizing, further, the necessity for starting the heavy construction work in connection with the earlier power developments, in order that the City might realize benefits from its power opportunities at the earliest practicable date, the Bureau of Los Angeles Aqueduct Power, in the Department of Public Works, was created in September, 1909, with Wm. Mulholland, Chief Engineer of the Aqueduct, as Supervising Engineer, and E. F. Scattergood, Electrical Engineer of the Aqueduct, as Chief Electrical Engineer. Soon after the organization of the Power Bureau a Consulting Board of Engineers, to consist of three Electrical and Mechanical Engineers of national reputation, was provided for, and Messrs. W. F. Durand, O. H. Ensign and Harris J. Ryan appointed. The duties of this Board consisted, in general, of an investigation of conditions at the various power sites, assisting in determining upon and in approving general plans for the development and transmission of power from all of the proposed power plants, passing on the detailed plans and specifications for all features of the works in connection with the development of the first installation of power along the Aqueduct and its transmission to the City, and passing upon the question as to what amount and at what location the first development should be made, together with the general character of the system for the distribution of the same in the City.

The City's agreement with these engineers has not as yet been terminated, and they are consulted in connection with all important features of the power work which the City is doing.

The General Plan of Power Development

The general plan for the development of the total power opportunities along the Aqueduct and on certain natural streams, as worked out by the engineers of the Power Bureau and adopted by the City, contemplates the ultimate development of at least 165,000 horsepower. By providing additional transmission circuits from the San Francisquito Canyon to the Owens Valley, the plans conform to the economical and reliable development and delivery of 200,000 horsepower at the City. The plans contemplate two separate steel tower transmission lines of an unusually reliable design and setting, supporting two electric circuits each, thus providing such duplication as to make complete interruption practically impossible and affording a degree of reliability, in conjunction with the numerous power plants located under reservoirs, far in excess of the reliability of the average power system of the present day.

The capacity of the four power plants along the Aqueduct, by switchboard measurement at the power houses, will be approximately as follows: 9,000 horsepower continuous capacity at the San Fernando plant; 44,000 horsepower of peak capacity at the second plant in the San Francisquito Canyon; 69,000 horsepower of peak capacity at the first plant in the San Francisquito Canyon; and 6,000 horsepower of continuous capacity at the power plant just below the Haiwee reservoir.

Owing to the close proximity of the two large plants in the San Francisquito Canyon to the point of use in the City, considering the transmission voltage of 100,000 volts, excellent regulation will be possible without steam plants, and the plans contemplate that the machinery in these plants shall be constructed in accordance with specifications requiring close regulation and ample allowance in K. V.

A. capacity for the electric generators to take care of the idle current until such time as the complete system is in large part developed, when it is contemplated that the synchronous condensers will be a desirable addition to be installed at the central substation in the City.

Power Funds Provided

The issuance of power bonds in the amount of $3,500,000 was authorized in April, 1910, and after much delay, due principally to court proceedings, the funds became available in April, 1912. $3,500,000 was manifestly but a part of the funds necessary to provide for the development of an appropriate amount of power and the distribution of the same in the City in conformity with the popular demand, but was all that the provisions of the Charter would permit at the time. In March, 1911, the Charter was amended so as to permit the authorization of power bonds in larger amounts. Public sentiment having been expressed by a vote on two occasions overwhelmingly in favor of the municipal distribution of the City's power, plans were determined upon with a view of developing an appropriate amount of power for supplying a municipal distributing system in the city, and the providing of such a system by purchase or by installation, and proceedings were initiated in September, 1911, for providing the necessary funds in addition to the $3,500,000 of power bonds previously authorized. After long delays, due to negotiations with local power companies and determined opposition of power interests to the establishment of a municipal system, $6,500,000 additional power bonds were authorized in May, 1914, for the completion of the first installment of power development and providing for the distribution of the same to the city and its inhabitants by purchasing existing electrical distributing systems, if possible, or otherwise by the installation of such a system.

Extent of First Power Development

After the amendment of the Charter, in March, 1911, it was determined that the first installment of power generating works to be constructed should consist of the line of rock tunnels leading from the South Portal of Elizabeth Tunnel to the first power site in San Francisquito Canyon, approximately two and one-half miles in length; the line of rock tunnels, including two short siphons, between power site No. 1 and power site No. 2 and leading from power site No. 2 to the point where the Aqueduct tunnels connect between the San Francisquito Canyon and the Dry Canyon Reservoir, a total distance of approximately seven miles; a surge chamber between the end of the line of tunnels leading to power site No. 1 and the steel pressure pipes leading to the power house at No. 1 site, together with pressure pipes and power house machinery necessary for the development of 37,500 horsepower at that point; necessary 100,000 volt transmission lines and switching station, and a central receiving substation within the City. The estimated cost of these works was $4,750,000, and the additional cost of completing the installation at power site No. 1 and at power site No. 2, thus increasing the total amount of power to 113,000 horsepower at the plants, or approximately 105,000 horsepower at the central receiving substation in the City, is approximately $2,000,000, thus making the total investment cost delivered at the central substation less than $65 per horsepower for this portion of the City's proposed hydro-electric power.

The general character of the hydraulic works in connection with the proposed developments of power at the No. 1 and No. 2 power sites in the San Francisquito Canyon between the Fairmont and Dry Canyon Reservoirs are illustrated on the accompanying diagram entitled "Hydraulic Development of San Francisquito Power Plants No. 1 and No. 2." The general character of the intake gate tower in the Fairmont Reservoir, the surge chamber now being constructed at the No. 1 power site, and the power house building are shown to a true scale. It has not been definitely determined as to whether there will be a surge chamber or a small reservoir for fore-bay capacity provided at the No. 2 power site, when power installation is made at that point. The exact amount of the gross head at this location will

depend somewhat upon which form of construction is finally decided upon in the future.

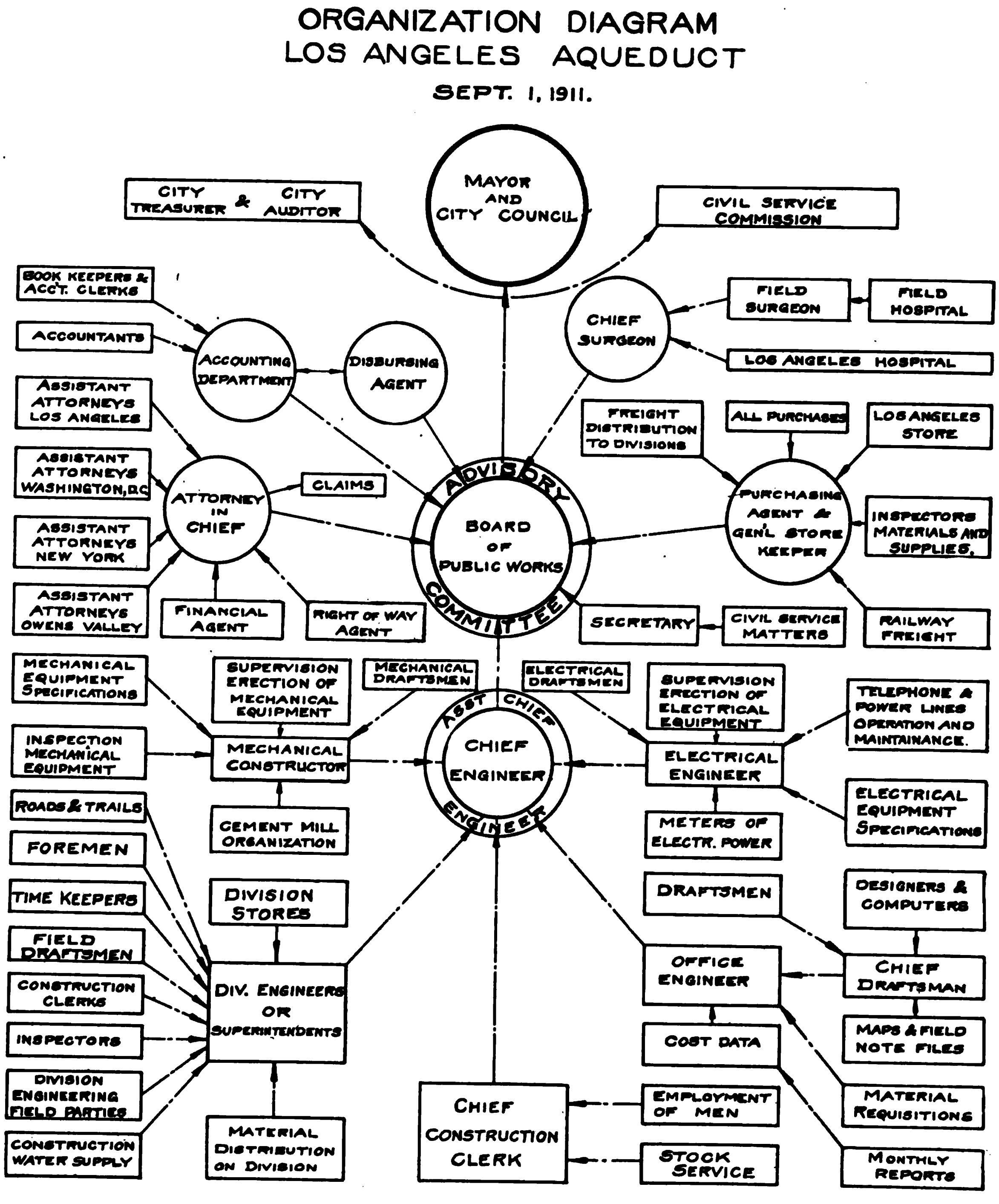
Transfer of Electric Works to Department of Public Service

The provisions of the City Charter, as amended in 1911, contemplated that the Board of Public Service Commissioners shall have full charge of all and any electric power generating and distributing works which might belong to the City. In December, 1914, the Board of Public Works, having completed the construction of the electric works provided for by the $3,500,000 of funds derived from the sale of the power bonds authorized prior to the amendment of the Charter in March, 1911, the city's electric works and Power Bureau organization was transferred from the Department of Public Works to the Department of Public Service, and the Bureau of Power and Light, operating under the direction of the Chief Electrical Engineer, was created in the Department of Public Service. The completion of the city's electric generating and distributing system, as well as the operation, maintenance and extension of the same, will be under the direction of the Board of Public Service Commissioners.

Steps Taken Toward Providing a Municipal Distributing System

The $6,500,000 power bonds authorized in May, 1914, were approved by the people with the definite understanding that $5,250,000 of the funds derived from the sale of such bonds would be used for providing a municipal electric distributing system in the City by the purchase of existing distributing systems, if possible, or otherwise by the installation of such a system throughout the city for the distribution of the City's power for the use of the City and its inhabitants.

The local power companies having positively refused to sell their distributing system to the City after many months of negotiations on two occasions, the City Council and the Board of Public Service Commissioners, in response to the mandate of the people to provide a distribution system by purchase or installation, instituted proceedings before the State Railroad Commission in November, 1914, for the fixing, by the Commission, of the just compensation which should be paid the Southern California Edison Company by the City for its electrical distributing system within the City, by condemnation, in accordance with the Public Utilities Act of the State of California.



This Plan of Organization Was Followed Throughout Construction

ORGANIZATION

The Mayor and Council are the executive and legal head of the City Government. The Mayor appoints the Board of Public Works, which consists of three members, whose selection is subject to confirmation by the Council. All ordinances have to originate with the Council, subject to approval by the Mayor. The City Auditor, and City Attorney, while occupying elective positions, work with and are advisory to the Council. The Civil Service Commission, which has appointive and removal power over all positions except those exempted in the Charter, is appointed by the Mayor and approved by the Council.

The Board of Public Works, under the provisions of the Charter, had charge of the expenditure of all bond moneys derived from the sale of Aqueduct and Power bonds. The actual organization, that was built up for the construction of the Aqueduct, was under the direction of the Board of Public Works, with the exceptions noted above. At the time the Aqueduct bonds were voted, the Board of Public Works consisted of J. A. Anderson, Chairman, D. K. Edwards, and Albert Hubbard. After the retirement of Mr. Anderson and Mr. Edwards, the Board consisted of Albert Hubbard, Chairman, Lieut. General Adna R. Chaffee, and Wm. Humphries. Subsequent to January, 1913, the Board consisted of Albert Hubbard, Chairman, Edward Johnson and Lorin A. Handley.

The City Water Works, which has charge of the distribution of the water in the City of Los Angeles, is a separate organization, under the Board of Public Service. Mr. Wm. Mulholland has been Chief Engineer and Superintendent of the City Water Department from the time it was taken over by the municipality in 1902, and was Superintendent and Engineer of the privately owned plant for years preceding that date. Mr. Mulholland was appointed Chief Engineer for the building of the Aqueduct by the Board of Public Works, and therefore reported to both these Boards. Mr. J. B. Lippincott was appointed Assistant Chief Engineer, July 1st, 1906, and was connected with the building of the Aqueduct from the preliminary surveys to its final completion in the summer of 1913.

The attorney for the Aqueduct, Electrical Engineer, Chief Accountant, Disbursing Agent, Chief Surgeon, and the Purchasing Agent and Storekeeper, all reported directly to the Board of Public Works.

In order to direct the work in a comprehensive manner, the Board of Public Works created an Advisory Committee, which consisted of the three members of that Board, the Chief Engineer and the Assistant Chief Engineer, the Aqueduct Attorney, and during the latter part of the construction, subsequent to the voting of power bonds, the Electrical Engineer. The Board of Public Service also was represented on the Advisory Committee by its President, because of the necessary close connection that existed between these two departments. This Advisory Committee met twice a week, and its minutes were transmitted to the Board of Public Works at its official sessions and officially adopted at its regular meetings, so as to become the legal action of the Board. From January, 1908, to January 1st, 1913, General Adna R. Chaffee, as a representative of the Board of Public Works, was the Chairman of the Advisory Committee, and was detailed by that Board as the executive head of the Aqueduct. General Chaffee, during his membership of the Board, gave most of his time to detailed supervision of the various departments of the Aqueduct, through the period of heavy construction. The Board of Public Works, in addition to the building of the Aqueduct, had charge of many other public improvements in the City, including the building of the Harbor, all street work, and public buildings.

In order to have a complete and independent check on the expenditures of the building of the Aqueduct, it was deemed advisable and necessary that the Aqueduct Auditor, Disbursing Agent and Attorney should report independently to the Board of Public Works.

Under the City Charter, all appointments to office and dismissals, together with all promotions, are subject to the regulations of the Civil Service Commission. A rigid interpretation of these provisions would have led to a great deal of embarrassment on the work, but the Commissioners recognized that in a construction campaign, in which the organization was rapidly expanded and reduced, and moved from place to place and from one class of work to another, it was impossible to comply strictly with civil service laws. They were satisfied that no attempts were being made to build up a political organization, and that efficiency was the only standard recognized. Consequently they liberally interpreted the provisions of the Civil Service Law. Examinations were held frequently for the various positions necessary on the Aqueduct, and men were always taken from the Civil Service lists when they were available. Many occasions arose, however, for emergenry appointments, but these appointees were subsequently required to take Civil Service examinations. Only in a few instances did such emergency employes fail to qualify in the examinations. All engineering, clerical and executive positions in the field, down to the foreman, were under Civil Service requirements, but mechanics and laborers were exempt. Throughout the entire organization of the Aqueduct, there was never an appointment made as the result of political influence. The Civil Service, on the whole, was a decided benefit to the work, because attempts to influence appointments were always met with the statement of the Civil Service conditions and the applicant instructed to take the regular examination.

Each Division Engineer had his own headquarters organization, with his division chief clerk and several superintendents, in charge of various features of his work. He maintained his own telephone exchange, store and machine shop. The policy was adopted of making these division chiefs responsible for all the work on their division and insisting only on efficiency and economy. They made their own requisitions on the General Store Department, prepared their own pay rolls and kept their own cost accounts. These were all subject to review and checking in the Los Angeles office. The division engineer was practically a Chief Engineer of his portion of the work.

Mr. H. A. Van Norman had charge of the construction work done with dredges and the building of the unlined canal on the Owens Valley division.

Mr. O. W. Peterson had charge of the construction of the open lined canal from the north end of the Alabama Hills to the Haiwee reservoir. This was a steam shovel job, and Mr. Peterson maintained as many as five steam shovels. His work was difficult, but was expeditiously accomplished.

Mr. Phil Wintz had charge of the building of the South Haiwee Dam.

Mr. C. H. Richards had charge of the construction of the covered conduits and tunnels in the Rose Valley and Little Lake divisions.

Mr. F. J. Mills was Division Engineer of the Grapevine division, which was a very heavy division, consisting of tunnels and pressure pipes.

Mr. Louis Mesmer built the Freeman Division.

Mr. A. C. Hansen completely constructed the Jawbone division and a large portion of the Mojave division.

Mr. John Gray had charge of the greater portion of the construction of the Elizabeth Tunnel and of the power tunnels in the San Francisquito Canyon.

W. C. Aston was in charge of the south portal of the Elizabeth tunnel.

Mr. D. L. Reaburn built the Saugus division, consisting largely of tunnels and steel pipe.

Mr. E. F. Scattergood was Electrical Engineed in charge of construction of power plants.

Mr. Roderick MacKay, with the title of Mechanical Constructor, had general supervision of the operation of the cement mill and of the selection and installation, in an advisory way,

DIVISION HEADQUARTERS AT LONE PINE, OWENS VALLEY. MT. WHITNEY IN DISTANCE. ALABAMA HILLS IN FOREGROUND

of most of the heavy mechanical equipment. Mr. MacKay's detailed and practical knowledge of mechanical affairs was invaluable to the building of the Aqueduct.

Mr. John Anderson held the position of Chief Steam Shovel Operator. He selected all the steam shovel crews and was responsible for the maintenance and operation of all the shovels on the line. He was a practical shovel man and his services were invaluable to the City.

Mr. E. W. Bannister, for a period of four years, was Office Engineer in general charge of the drafting room and of the office records. Mr. W. W. Hurlbut was Chief Draughtsman in charge of all maps and field notes, and was particularly detailed to all rights-of-way matters. Mr. Edward R. Bowen, under the direction of the Chief Engineer, prepared the designs for most of the structures on the Aqueduct. Mr. S. B. Norton was Chief Clerk of the Engineering Department and had largely to do with the office correspondence and the direction of the field clerical organization.

Mr. O. E. Clemens, in co-operation with the Aqueduct Auditor and the Assistant Chief Engineer, developed a cost keeping system for the Aqueduct.

The accounting method adopted on the Aqueduct was that used in the Construction Department on the Harriman railroad lines. Mr. W. M. Nelson, one of the Auditors of Disbursements for this road, was obtained from the Southern Pacific Company when the Aqueduct was organized, and spent about two years on the work of installing the system. After his return to the railroad company, this department was placed in charge of Mr. E. V. Harding, who efficiently directed it until his death, which occurred subsequently to the completion of the work. This system, which has been the development of years of experience on the part of the railroad company, while somewhat elaborate and cumbersome, is very effective. During the expenditure of the entire fund, both of the Aqueduct and Power Bureaus, amounting to some 28 million dollars, no scandal occurred. The entire field and office records of the Aqueduct were subject to a most severe and unfriendly investigation by opponents, and after six months of vigorous research, nothing worthy of criticism, relative to the disbursement of funds, was found.

Mr. L. E. Moselle acted as Disbursing Agent throughout the period of construction.

Mr. W. R. Ormsby was in charge of the purchasing and store department. All purchases were made on competitive bids, with but very few exceptions, which were specifically authorized by resolutions of the City Council. Bids were advertised for in most instances.

A complete hospital department was organized and maintained during the construction of the Aqueduct. This work was let by contract in May, 1908. Dr. Raymond G. Taylor was in charge of it practically throughout the entire period of construction. Field hospitals were built at nine points on the line, at which medical stores and attending physicians were maintained. At all large construction camps medical stewards were located, who looked after the sanitary conditions and treated minor cases, rendering first aid. Severe injuries or serious cases of sickness were sent in to the California Hospital at Los Angeles.

The Medical Department was held responsible for the sanitation of the line, and a very small amount of sickness occurred on the work. No epidemics of any kind were experienced. From the pay of all employes, $1.00 per month was deducted for medical attendance, except where the monthly pay check amounted to less than $40.00, in which event 50 cents was deducted. The medical service rendered was efficient, prompt and satisfactory.

Up to August 1, 1908, the Aqueduct maintained its own commissary department in the field, and made a charge of 25 cents per meal for all meals furnished. Subsequent to that date, a contract was awarded to D. J. Desmond for subsisting all field employes at a charge of 25 cents per meal, except at the cement plant, which had already been fully equipped for subsistence purposes and where the City maintained its own organization. It was found that the time, attention and worry involved in maintaining these commissary institutions distracted the attention of the Aqueduct organization

too much from the immediate purposes of the work.

The cost of living increased steadily, and the commissary contractor found it impossible to furnish satisfactory meals in these scattered and remote camps for the contract price. The contractor ran behind until he had accumulated many thousand dollars of debts, and it was a question of whether the Board should help him out of his difficulty or permit him to fail and leave a very involved and unsatisfactory condition of affairs in the field camps. Consequently, in October, 1910, the Board, after a study of prices and the contractor's books, authorized an increased charge for meals to 30 cents. The alternative would have been for the Board to have bought all of the equipment of the contractor, which would have amounted to more than $100,000.00, and to have run the commissary for the remaining portion of the work.

During Mr. Desmond's financial embarrassment, considerable complaint was made as to the quality of the meals, but after the advance to 30 cents was made, the meals were satisfactory and little complaint was heard. The meals served on the Aqueduct were substantial in quality and adequate in quantity, except in unusual instances, and while the question of letting a boarding contract for work of this kind is subject to discussion, on the whole it is believed that the meals served on the Aqueduct were substantially superior to most meals supplied on public work.

The City furnished sleeping tents and bunks for the laborers, but the men supplied their own bedding. Married men, with their families in the field, were supplied either with houses or individual frame tents with floors, but in this case they were charged a rental sufficient to return either the full price of the tent or two-thirds of the cost of the house, it being estimated that the remaining one-third of the cost of the house could be obtained in salvage after the completion of the job.

A striking feature of the Engineering organization of the Aqueduct was its simplicity and the very low cost of administration and supervision of the work. The Division Engineer, who was expending from $50,000.00 to $75,000.00 a month, was usually supported by a division chief clerk and two or three clerical assistants at the division headquarters. One clerk was maintained in each field camp. The duties of these clerks were to handle all the pay rolls, time checks, material accounts and cost data. Usually one surveyor, with from two to three assistants, did all of the surveying work that was necessary for the division. Each camp of 50 men or more was in charge of a foreman or camp superintendent. In the executive office there was the Chief Engineer, Assistant Chief Engineer, Office Engineer and the Chief Clerk of the Engineering Department, with two assistant clerks and four men in the Cost Division. The drafting room seldom contained more than four or five men.

Taking the month of June, 1912, at random from the accounts of the Aqueduct, we find a total expenditure for pay rolls, livestock, materials and freight of $373,614.00, and that division administration amounted to 1.6 per cent. of this amount, or only 3.2 per cent. of the pay roll charges alone; these pay roll charges being $182,387.00. The cost of sanitation and housing amounted to 0.7 per cent. of the total expenditures. The cost of handling materials through the local stores amounted to 2.5 per cent. of the cost of material, and the ratio of division administration, including executive charges, sanitation and housing, and material handling, was 3.2 per cent. of the total expenditure. The executive expenses of the Los Angeles office, including general expenses, the Engineering Department, Electrical Department, Legal Department, Disbursing and Accounting Departments, Advisory Committee, Traveling Expenses, Rents, Miscellaneous Expenditures and Supplies for this month amounted to 2.56 per cent.; the drafting room .13 per cent.; purchasing and store department .34 per cent.; maintenance and operation of automobiles .38 per cent.; passenger transportation .40 per cent.; or a total of 3.81 per cent. The grand total of these field and office charges amounted to 7 per cent. All of this work was carried on by day labor and not by contract, and full and complete en-

TYPICAL DESERT CONSTRUCTION CAMP. 3500 MEN WERE MAINTAINED IN THESE CAMPS DURING BUILDING OF AQUEDUCT

gineering and labor supervision of the entire enterprise was covered by this 7 per cent. Such costs usually approximate 10 per cent., when the work is done by contract, in which event the contractor has an additional percentage to add to cover his own administration charges.

Contract Work

The only portion of the Los Angeles Aqueduct built by contract consisted of 11 miles of canal and 1,485 feet of tunnel between Fairmont reservoir and the south end of the Antelope Valley siphon. This contract was awarded to P. A. Howard, December 12, 1908. The City supplied all cement at the railroad station, lumber and steel, built main roads, laid the pipe lines and built the telephone line. The contractor furnished all labor, equipment, miscellaneous supplies, such as powder, oil, etc., and the equipment and buildings required for his work.

Bids were called for in order to compare contractors' figures with the estimates for work to be done by the City, and while it was realized that the prices asked were higher than the work could probably be done for by day labor, it was considered fair on the part of the City to let the contract, after the contractors had gone to the trouble to submit their bids.

The contract work subsequently cost more than was indicated by the bids, because of certain unavoidable changes that were made in the plans, for which the contractor had to be paid at a price bid per yard for extra concrete. Under the contract, the average cost per foot for the covered Aqueduct was $14.30. The cost of similar work done by the City's force under conditions where the concrete aggregates, length of haul, etc., were practically the same, was $10.50 per lineal foot for direct field charges. To this must be added the cost of equipment, buildings and tents, which amounted to 60 cents per lineal foot, making a total cost for work done by the City by day labor of $11.10 per foot as compared to the cost of $14.30 per foot paid to the contractor. In other words, the City work cost 78 per cent. of the cost of the contract work. The auxiliary charges, which had to be paid by the City, were practically the same in both cases, and the time required for directing the work was greater in the case of the contract job than where the City superintendent was directly in charge of the work.

The advantage of doing work by day labor or force account lies particularly in the freedom with which plans can be changed and the line modified to meet conditions as they develop during construction. In addition, when work is being done by day labor, it can be done faster when funds are available, or greatly reduced in case of financial stringency, without damage claims from the contractor. The work done by contract was not more satisfactory than that done by day labor.

Bids were asked for the building of the Jawbone division by contract, but they were so much in excess of the estimates of the Engineer, even after allowing for 15 per cent. profit for the contractor, that they were all rejected, and the work on the Jawbone division was finished for several hundred thousand dollars less than the lowest price bid.

COST-KEEPING AND ACCOUNTING

Cost keeping is an engineering study. It relates to the current "unit costs" of the performance of construction work, rather than the total monthly or aggregate cost of such work. To determine the unit costs, it is necessary that the accounts be kept by some one who has the progress records at hand and who has an intimate knowledge of the construction. The engineer, aided by a knowledge of the accounting system used, or by a competent accountant, must develop this class of record. The place for the origin of cost records is the Division Engineer's Headquarters.

The proper foundation for a cost keeping system is the "Work Order." This is a specific authority from the Chief Engineer or governing officer for the performance of a definite piece of work. This work order, as used on the Los Angeles Aqueduct, was developed as follows:

Before any expenditure for work on a division was made, the Division Engineer sent in a request to the Chief Engineer for authority therefor, either furnishing an estimate of the cost, or data sufficient to enable the office to make an intelligent estimate. These estimates were then checked and submitted to the Chief Engineer for approval. The Engineer's recommendation was submitted to the Board of Public Works, and when approved, work orders were issued by the Chief Engineer, and copies sent to the Accounting Department and the Field Engineer affected.

Monthly Reports

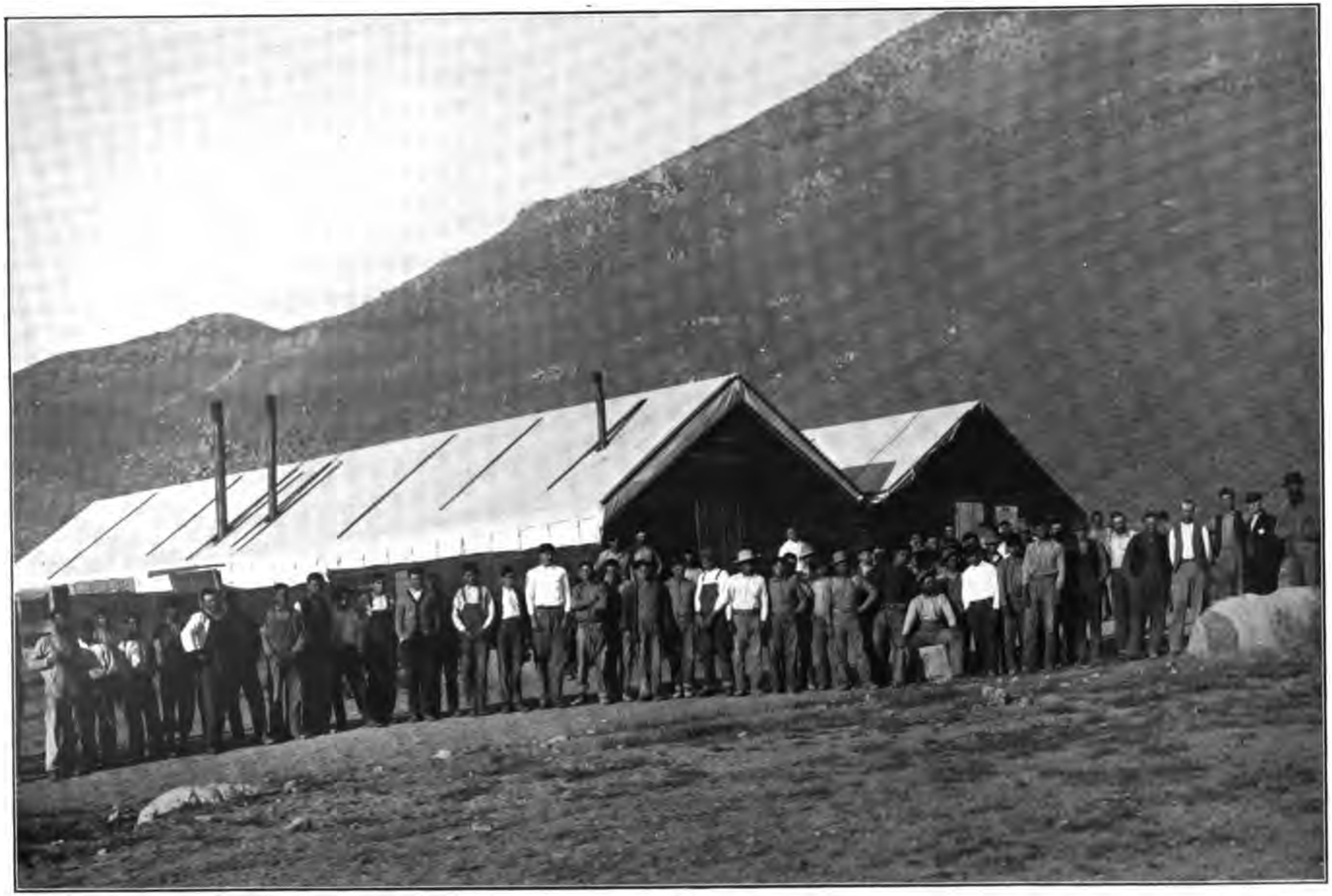
From the labor distribution sheets, material diaries, stock service reports and miscellaneous bills, detailed monthly cost reports were made by the division clerks for each work order in progress. All charges were reduced to unit costs.

These monthly cost reports from the division office were checked against the labor distribution, material diaries and other reports. They were then compiled into a general monthly cost report for the entire Aqueduct by the engineer in charge of cost data, who prepared therefrom a monthly bulletin showing the division, the engineer in charge of the division, the foreman in immediate charge of the construction under a given work order, a description of the work performed, the monthly progress and unit costs, also the total progress to date and total unit costs. The engineer's estimate was given in parallel. The engineer in charge of costs also prepared a digest of the monthly report, calling attention to any work which he considered especially important for the Chief Engineer to note; whether it was being done at an unusually low figure or an excessively high one, placing detailed data at the disposal of the Chief Engineer.

This condensed monthly report was distributed monthly throughout the entire field organization, so that each foreman or superintendent knew whether he was doing cheaper or more expensive work than his associates. It was found that these monthly reports were not only of value to the Chief Engineer, but that they became a stimulus to the men in the field. The fact that the work was advertised in this way was a matter of great concern to the field officers, and corrections of the working differences were usually made by the men in charge before the Chief Engineer had occasion to take action in the matter.

Labor Charges

The foundation upon which the labor distribution rested was a daily time card. Each man was required to make out a time card every day, on which was stated the work order and class chargeable, and if he had worked on more than one piece of work, the amount of time given to each. This card at the end of the day's work was taken to his foreman, approved by him, and deposited with the timekeeper at the construction camp.. These time



WAITING FOR SUPPER AT MESS HOUSE. THESE MESS HOUSES WERE PORTABLE

cards were assembled by the construction clerk in the camp, and grouped on individual time rolls in such a way as to distribute the labor in accordance with the classifications shown on the work order. From the individual time rolls, the regular pay rolls were made up and forwarded to the Accounting Department, where they were audited and pay checks made out.

Stock Service Charges

To simplify the accounting and insure an equitable and accurate charge for stock service, a general operation account for live stock was adopted. To this was charged all expenses affecting cost of live stock service. This charge, from over four year's experience, shows 90 cents per animal day on the Aqueduct, including mortality and depreciation.

Materials and Supplies

All purchases of material originated by requisition, which was signed by the Division Engineer or Superintendent, and approved by the Office Engineer or Chief Storekeeper.

When purchased, the goods were shipped direct to the division requiring them, or in case of stock articles, were delivered to the Los Angeles Warehouse. Engineers desiring shipments from the Los Angeles Warehouse made a warehouse requisition, which was approved by the Office Engineer and Chief Storekeeper before being filled by the local storekeeper. Shipment was then made to the division and record made on a Department Transfer.

The material on each division was carried in a division warehouse. When the foreman on the work required supplies, he requisitioned them, in duplicate, noting the work order to be charged.

On the first of each year an inventory was made of all material on hand in the different warehouses. These were matched against the ledger balances shown in the Accounting Department against the several divisions. The first year's business on the Los Angeles Aqueduct showed a shortage of material used, but not reported, but an analysis by the Cost Division of the work orders in effect during the period served to locate all but a small percentage.

Freighting Expense

On account of the transferring of materials and equipment to the various warehouses and the long wagon haul in some places, it was difficult to include the freight in the price of materials when billed to the work. All freights were charged to a general freight account and cleared each month by Department Transfers based on materials issued to the work during the month, as shown by the Material Diaries. This computation was based on the class of materials, railroad and wagon haul, a schedule of rates being worked out for each camp.

Shop Operations

Each machine shop had a work order to which was charged all shop labor, material and miscellaneous supplies. When work was to be done at the shop, an order was given. The clerk then issued a shop card to the foreman, who entered on it the labor and material expended on the job. The small supplies, such as coal, oil, waste, tool repairs, etc., together with the foreman's and clerk's time, were charged in bulk to the "Overhead Expense." This overhead expense was distributed at the end of the month over the shop work done, on a percentage basis. A department transfer was then issued, crediting the shop operation work order and charging the division for which the various jobs were done.

Electrical Energy Charges

This was handled the same way as the shop work, work orders being issued to receive the charges for maintenance and operation of the several power plants and transmission lines. This energy was billed on the basis of meter readings at the various construction camps at a price per kilowatt hour sufficient to cover all maintenance and operation costs and plant depreciation. When the accounts were cleared at the end of the job, all expenses of producing power were taken care of and equitably distributed to the work receiving benefit.

Cement Manufacture

The City operated one cement mill and three tufa cement mills, an operation work order being issued for each mill. This work order was charged with all operation costs and depreciation, and was credited with the value of the product which was billed to the Division, Material on Hand Accounts receiving it. This price was fixed periodically, as cost of production warranted.

All Department Transfers for energy, shop work, etc., were checked by the Cost Division and Accounting Department for proper credit and debit to work orders and material accounts before being entered by the Accounting Department. A temporary register was kept by the Cost Division of the credits and debits to work orders to serve as a check against field cost reports.

Progress Reports

Ten-day reports were forwarded by each division to the Cost Division, where they were assembled and made the basis of general progress statements, progress diagrams, profiles and records. The monthly cost reports were also checked against these progress reports to guard against errors in unit costs. In addition to these reports each foreman was required to furnish, at the close of each ten-day period, a detailed report of material used, work done and conditions of ground.

Equipment Expense

On the Los Angeles Aqueduct, owing to the diversity of work and numerous different pieces of work handled at the same time, it was not practicable to charge the equipment direct to each job. The work had to be divided into 13 divisions. To each division were issued equipment work orders, to which was charged all equipment taken into the division, work orders being issued for the several classes of equipment, as follows: Livestock; vehicles; traction engines, miscellaneous construction equipment, which included all tools and other floating equipment; camp equipment; compressor plants; tramways and trolley roads. This arrangement showed, by the work order charges, the total amount tied up in the various classes of equipment. There was issued to each division an "Expended Equipment" work order. To the "Expended Equipment" work order was charged the value of equipment worn out or condemned, and the "Salvage Loss" or "Depreciation" on any equipment transferred off the division, proper credit being given to the equipment work order originally charged. This "Expended Equipment" work order, when the division was completed and all equipment released, represented the actual net cost of equipment to the division.

When equipment was transferred from one division to another, an equitable valuation was assumed, based on first cost and present condition.

Auxiliary Construction

Work orders were issued for buildings, pipe lines, etc., to each division. In the event of a transfer from one division to another, of materials in these structures, a nominal transfer value was given. When the division was completed and all salvageable materials removed, the balance remaining in the work orders represented the cost to be pro-rated.

Administration Expense

To simplify distribution of this expense, and also to keep the Executive Office informed as to the exact outlay of this nature, instead of having it concealed by distribution in each month's operations, a work order was issued to each division for "Division Administration" carrying the following classifications:

A—Administration—Division Engineer, Executive Assistants and camp clerks.
B—Sanitation and Housing—all camps.
C—Traveling Expense Accounts.
D—Material Handling Expense—Warehousemen.

Semi-Annual Estimate

Twice a year a general estimate was made, in which was shown the amount accomplished under each work order, the total and unit costs

thereof, and the amount remaining to be accomplished. With the knowledge of the physical conditions of the unfinished work, together with unit cost data for work that had already been done, it was possible to make an estimate of the cost to complete the entire project.

Accident Claims

The number of serious accidents and fatalities connected with the building of the Los Angeles Aqueduct was surprisingly small. About five million pounds of powder were used in the driving of the tunnels and in other excavation work, and but five deaths resulted from explosions, or one man to the million pounds of powder burned. Great care was exercised in the handling of explosives, and the highest grade of fuse and high-grade caps were used exclusively, so that very little powder exploded in an uneven manner or was left unexploded in the work.

The total number of accidents resulting in death were 43; the number resulting in permanent injury but one; and the total number of miscellaneous accidents, most of which were of a trivial character, amounted to 1282, or a grand total of 1326 accidents.

The orders to the field superintendents were that all accidents, no matter how trivial, should be reported in detail and statements obtained, not only from those injured, but from all witnesses, in order that the records might be complete. All men going to work were required to sign a Memorandum of Employment, agreeing to go to work for a certain definite wage and to permit deductions being made for board and hospital fees. In the case of disability due to an injury, the men were maintained in the hospital and furnished free board and half pay.

The total amount expended in the settlement of all claims was $32,542.58, for a total pay roll on the entire job of $12,379,340.00. The ratio of accident payments to the total pay roll was, therefore, .263 or 26.3 cents on each $100.00. These are figures compiled in July, 1912, at a time when the Aqueduct construction was about 90 per cent. finished. At that time there were two unsettled claims pending in court, neither one of which actually came to trial. But one case was ever permitted actually to come to trial in court. In this instance there was a strong indication of fraud on the part of the claimant, and subsequently it was found that fraud did exist in the claim.

At the beginning of the work, the Board of Public Works was urged by a casualty company to take out insurance covering these damage claims, and the rate offered was 95 cents per hundred dollars on the pay roll. The actual cost to the City, therefore, in settling these claims, was but little more than one-fourth of the insurance rate, but all money that was expended on this account went directly to the men, which is not always the case where casualty insurance is taken out.

FINANCES

The funds for building the Los Angeles Aqueduct could, of course, only be provided by the issuance of bonds against the credit of the city. The amount required seemed at first appalling. No other city of the same size, however urgent the necessity, had ever asked for so large a loan. The people saw that Los Angeles was nearing the limit of her possible development upon the existing water supply. They realized that the rapid strides with which she had passed from the condition of an obscure village to a place of real prominence among American municipalities must soon slow down; that, in fact, she must be prepared to come, within a very few years, to a standstill, if not to the point of actual retrogression, unless more water, in abundant quantity, were provided without delay. All this the people of Los Angeles clearly saw and they were ready with practical unanimity to do everything in their power to meet the situation, but when told that nearly $25,000,000 would be needed to solve the difficulty confronting them, they said—rather, they almost said—impossible! The lenders of money would pronounce the scheme for bringing water through mountain and desert, a distance of 233 miles, fantastic and impracticable. They would not allow their usual conservative methods of selecting securities to be affected either by the needs or the courage and determination of a people seeking money for a great public enterprise. They would at least exact a ruinous rate of interest, and make the proposed debt too onerous to assume. All these and other imaginary difficulties entered into the popular mind as it contemplated the plans and estimates of the engineers for bringing an additional water supply from Owens River Valley to Los Angeles. However, the city, in seeking to negotiate a loan for the aqueduct was fortunate in possessing a very important resource in addition to its assessed value of property.

Los Angeles, in 1902, had purchased from a private company the system by which the greater part of the city had been supplied with water, and, for that purpose, had issued and sold $2,000,000 of bonds. This venture proved extremely successful. Under municipal operation the revenues, besides taking care of the operation and ordinary improvements and extensions, were sufficient to pay all charges for interest and principal of the water debt. Even more than this was accomplished. Practically the entire system, which, as a result of the rapid growth of the city had become inadequate or obsolete, had been rebuilt with larger mains, out of the water revenues, and without a cent of taxation. This record of municipal ownership was exhibited in the money market with noticeable effect on the attitude of the bond houses toward the request of Los Angeles for financial assistance in carrying out her aqueduct project. It soon appeared that the necessary funds might be secured.

In September, 1905, a bond issue in the amount of $1,500,000 was authorized by a vote of the people, in the ratio of 14 to 1, for the purchase of the necessary lands, water rights and rights of way, and for engineering and investigations necessary to develop the complete plans of the aqueduct project. This issue, which ran for a maximum period of forty years, carried 4% interest, and was sold by the city, under competitive bidding, to N. W. Harris & Co., of Chicago.

The estimates of the board of expert engineers, composed of John R. Freeman, Frederick P. Stearns and James D. Schuyler, as set forth in a report of December 22, 1906, placed the cost of constructing the aqueduct at $23,000,000, exclusive of the expenditures for the purposes covered by the bond issue of $1,500,000.

At the time the aqueduct project was being financed, the municipal charter limited the bonded debt of the city for ordinary purposes to 3 per centum of the assessed valuation of all taxable property, with the addition of not to exceed 12 per centum thereof for the more important improvements, including water works. In 1906-7 the assessed valuation of the city was $203,441,028, and its total bonded debt amounted to $7,000,000. To add to this the $23,000,000 required for the aqueduct would mean practically the exhaustion of the city's legal credit.

The question was raised at the outset of the proceedings for authorizing the aqueduct bonds, whether the whole amount should be covered in one issue of bonds or should be divided into installments to be voted on separately by the people as funds might be needed. The latter plan seemed to present the advantage of a gradual assumption of the aqueduct debt, and avoidance of the objection that the public interests required the maintenance at all times of a substantial margin between the debt limit and the total debt of the city. However, it was concluded that authorization of the entire aqueduct issue at one election would be the wiser and safer course, and this was adopted.

On June 12, 1907, after a campaign of education enlisting the efforts of all available agencies for stirring the interest of the people and creating sentiment in favor of the aqueduct bonds, the whole issue of $23,000,000 was authorized by vote of the people in the ratio of 10 to 1.

The firm of Dillon & Hubbard, attorneys of New York City, and experts of the first rank on municipal law, were employed by the city to supervise all proceedings for the authorizing of the aqueduct bonds, and to issue their opinion to purchasers of these securities, certifying them to be the legal obligations of the City of Los Angeles.

With the voting of the aqueduct bonds Los Angeles found itself facing the great and well-nigh insuperable difficulties of initiating that enterprise and carrying it to a successful conclusion.

By order of the city council it was provided that the aqueduct bonds should be of the denomination of $1000 each, and should be payable in equal annual installments maturing in 7 to 40 years from date thereof, which was fixed at December 1, 1907.

W. B. Mathews, who had been City Attorney of Los Angeles for three terms, and had had a leading part in marketing the $2,000,000 of water works bonds of the city issued in 1902, was given charge of the work of finding purchasers for the aqueduct securities. Following his retirement from the office of City Attorney, in January, 1907, he had entered the municipal service under the title of "Special Counsel of the Los Angeles Aqueduct Bureau," an organization specially provided for by ordinance for the purpose of constructing the aqueduct.

While the logical market for the aqueduct bonds was located in the east, the bond agent decided that it would be good policy, before presenting them to foreign investors, to elicit a practical expression of home confidence in the credit of the city. Accordingly, he negotiated a sale to the State of California of $510,000 of aqueduct bonds as an investment for school funds and soon after effected a sale to Los Angeles financial institutions of a like amount. These blocks of bonds bore 4% interest. Then an attempt was made to move $340,000 of these bonds, of the denomination of $200 each and bearing 4% interest, by popular subscription, but this plan resulted in the disposal of only a few thousand dollars of the bonds. This failure to secure better results was due chiefly to the fact that investors in California are accustomed to receiving much higher interest than municipal bond rates, and, besides, at the time these $200 bonds were offered for sale, the county was still suffering from the effects of the 1907 panic, and consequently investors were timid and money was scarce.

Preliminary field work on the aqueduct started about October 1st, 1907. By spring, 1908, it was seen that the funds realized from the bond sales already mentioned would soon be exhausted, and that other sales must be effected without delay or the construction

forces on the aqueduct must be disbanded and the work stopped.

The bond agent, in this situation, was left to his own devices to procure additional funds. Believing that all possible had been accomplished locally, he repaired, in May, 1908, to New York for the purpose of urging the remaining aqueduct bonds upon the attention of dealers in that city.

On July 10, 1908, the council, upon the report and recommendation of the bond agent, authorized a contract with Kountze Bros. and A. B. Leach & Co. of New York City, covering the unsold portion of the aqueduct bonds, at 4½% interest, and providing for the sale outright of $4,085,000 of these bonds at par and a premium of one-fourth of one per cent and giving to the purchasers an option on the balance upon condition that the city, at the election of the purchasers, would deliver $2,856,000 at a premium of one-fourth of one per cent by February 1, 1909; $4,896,000 at a premium of one-half of one per cent by February 1, 1910; $4,896,000 at a premium of one-half of one per cent by February 1, 1911, and the remainder at a premium of one per cent by February 1, 1912.

This contract was advantageous both to the buyers and to the city. It had the effect of establishing the city's credit for the purposes of its great water enterprise and prevented a disruption of its construction forces, which would have involved a heavy loss through delays and impaired efficiency. Besides, the plan of issuing the bonds in installments covering a term of years made it possible for the city to keep its interest charges down to the minimum.

Upon completion of the delivery of the first block of bonds called for by the contract with the New York houses, the working forces on the aqueduct project were greatly increased and construction was energetically pushed, with the result that expenditures soon reached a scale in excess of the schedule of possible deliveries prescribed in such contract. It so happened that the general bond market was quite good and the purchasers were willing to exercise their options and accept deliveries ahead of the dates stipulated. This procedure, however, led to a very unfortunate situation.

In the early part of the year 1910 the market for municipal securities had become quite inactive, with the result that the holders of the options under the contract of July 10, 1908, insisted that further deliveries in excess of the schedule outlined in the contract should be suspended. The city took the position that any excess deliveries had been for the mutual benefit of the parties to the contract, and should be deemed part of the bonds to be last called for thereunder. The bond houses, on the other hand, insisted that such excess deliveries should be charged against the schedule in the contract, in regular sequence. In these circumstances, it was necessary for the city to provide funds from other sources in order to continue work on the aqueduct. This was accomplished by the sale of $1,326,000 of the bonds covered by the contract of July 10, 1908, into the sinking fund which had been established in connection with the aqueduct issue, and the further sale, with the consent of the bond contractors, of $1,000,000 of these bonds to the Metropolitan Life Insurance Company and the New York Life Insurance Company of the City of New York, in equal shares, and of $530,000 thereof to the contractors themselves. These sales, which were consummated August 12, 1910, left $2,892,400 of the entire issue unsold and covered by the contract with Kountze Brothers and Leach & Company.

On January 10, 1912, Kountze Brothers and Leach & Company gave notice to the city that they would not exercise their option on the remaining bonds under the terms of their contract. This action, whatever the reasons for taking it may have been, was calculated to seriously embarrass the city in its efforts to keep construction work going on the aqueduct. Fortunately, the city, since the aqueduct bond issue was authorized, had continued its remarkably rapid growth in population and assessed wealth. As to the former, the increase had been from 284,000 to 425,000 and as to the latter, from $203,441,000 to $391,341,000, and these facts were calculated to greatly facil-

itate the efforts of the city to dispose of the remaining unsold portion of these bonds.

Upon receipt of the notice from Kountze Bros. and Leach & Co. the bond agent proceeded to New York City to find new purchasers for the securities released by those concerns. Prior to that time the people of Los Angeles had authorized an issue of $3,500,000 of bonds for electric power development along the aqueduct, and an issue of $3,000,000 for the development of Los Angeles harbor, and it seemed expedient, if not necessary, that all three classes of bonds should be handled and disposed of together. Accordingly, the bond agent was authorized to affect a sale of all these securities, totaling $9,592.400. As the result of his efforts, within one month after Kountze Bros. and Leach & Co. had relinquished their option on the unsold aqueduct bonds, a contract was negotiated between the city and Speyer & Co., New York City, for the sale to that firm of $2,890,000 of aqueduct bonds (being the unsold portion of such issue, excepting $2400 permanently cancelled), and the bond and harbor issues just mentioned, at the price of par and accrued interest. All these bonds were delivered and paid for in accordance with the terms of the contract.

Thus Los Angeles, in the face of many serious difficulties, floated a bond issue of unparalleled magnitude to provide a water supply sufficient for her needs for all time to come.

COMPARISON BETWEEN ESTIMATED COST AND ACTUAL COST OF THE LOS ANGELES AQUEDUCT

The first issue of Aqueduct bonds was for the purchase of lands, water rights and for the making of surveys and investigations, amounting to $1,500,000.00, bearing 4% interest. A second issue of $23,000,000.00 was authorized for construction purposes. Of the second issue, $1,033,600.00 were sold bearing 4%, and $21,964,000.00 bearing 4½%. Premiums aggregating $77,010.00 were received from these bond sales. The total funds available, therefore, from the sale of the bonds for the Aqueduct amounted to $24,591,856.00. These funds were expended in the following manner:

Pay Rolls	$12,500,000.00
Freight and express	2,250,000.00
Lands and rights of way	1,700,000.00
Materials, equipment and miscellaneous charges	8,150,000.00
TOTAL	$24,600,000.00

The Board of Consulting Engineers, consisting of Messrs. Freeman, Stearns and Schuyler, on December 22, 1906, filed a report with the Board of Water Commissioners in which they estimated the cost of the Aqueduct at $24,485,700.00. They described the work to be done in detail. They planned an open, uncovered conduit throughout the desert section, not because the roof was considered unnecessary, but because funds were not available in their judgment, the estimate having practically covered the bonding limit of the City at that time. The Aqueduct engineers, however, realized that in a region where high winds prevail, as in the Mojave Desert, and where there is much drifting sand, a covered conduit was highly desirable, and the entire structure, with the exception of the flood water canal north of the Haiwee Reservoir, for a distance of 100 miles, was covered with reinforced concrete at a cost of $10,000.00 per mile, or $1,000,000.00. In addition, larger tunnels and the Dry Canyon Reservoir were built to aid in the development of water power, at an estimated additional cost to the Aqueduct of $650,000.00.

Lands and water rights were purchased in Owens Valley, in excess of the original plan, to the extent of $325,000.00. The City now owns approximately 125,000 acres of these lands, and they have increased in value since their purchase, largely because of the building of a railroad from Mojave.

On June 1, 1913, it was estimated that there remained on hand unsold equipment and excess lands worth at a reasonable market value, $190,000.00. The Aqueduct owns three hydroelectric power plants in Owens Valley that were built for the purpose of generating power for construction purposes. The City received an offer to purchase these plants, but the Board of Public Works considered it advisable to retain them. They remain an asset of the Aqueduct, valued at $150,000.00. The City owns the Cement Mill, with three limestone deposits, large clay beds and agricultural land of high grade, aggregating 4,300 acres, on portions of which artesian water may be obtained. The minimum selling price of this plant, with lands, is $550,000.00.

In short, the Aqueduct was built for the estimated cost, but $1,975,000.00 was invested in lands and betterments in addition to what was contemplated in the original estimate, and salvage material remained to the extent of $890,000.00, so that the original estimate may be said to have been beaten by $2,865,000.00.

The maximum number of men employed at one time, during the building of the Aqueduct, was 3,900; the maximum number of animals engaged in grading and construction was 1,355, and the maximum monthly expenditure was in May, 1910, when $575,000.00 was disbursed. The total length of the Aqueduct, exclusive of reservoirs and power conduits, is 215.54 miles, and including power conduits, penstocks and reservoirs, is 233.25 miles. Work was started

by hand at the earliest possible date (in October, 1907) on the Elizabeth Tunnel, because it was then considered the controlling factor in the work. General construction work, however, did not begin until the summer of 1908, and the Aqueduct construction was completed in May, 1913, or within the five-year period estimated by the Board of Consulting Engineers.

AQUEDUCT STATISTICS

BOND ISSUES

1st Issue $1,500,000—40-year Bonds.

Voted Sept. 5, 1905, proportion 14 to 1.
Interest rate 4%.
Sold to local concerns at par.
Proceeds applied to purchase of lands and making of perliminary surveys.

2nd Issue $23,000,000—40-year Bonds.

Voted June 12, 1907, proportion 10 to 1.

Interest rate:	$ 1,033,600	at 4%
	21,964,000	at 4½%
	2,400	not issued.
	$23,000,000	

Total premium obtained, $77,010.00.
Sold as follows:

State of California	$ 510,000
Local Banks	510,000
Metropolitan L. I. Co.	500,000
New York Life I. Co.	500,000
Speyer & Co., N. Y.	2,890,000
Kountze Bros. and A. B. Leach & Co. with exception of few thousands, which were sold locally	18,087,600
	$22,997,600

Proceeds applied to construction work.

CEMENT MILLS—OUTPUT

	Bbls.
Monolith Mill, Portland cement	920,000
Fairmont Mill, Tufa, Regrind cement	280,000
Haiwee Mill, Tufa, Regrind cement	250,000

Total concrete used, approximately 1,500,000 cubic yards.

LENGTH AND SECTIONS OF AQUEDUCT

		Capacity Sec. Ft.
Unlined Canal	23.726 miles	900
Open Lined Canal	37.054 miles	900
Haiwee By-Pass	2.001 miles	420
Covered Conduit	97.642 miles	420
Lined Tunnels	42.903 miles	420
Concrete Flumes	0.165 miles	420
Siphons	12.052 miles	420
	215.543 miles	

		Capacity Sec. Ft.
Power waterway	9.845 miles	1000
Reservoir	7.87 miles	
Total length intake to lower end of last tunnel above San Fernando Reservoir	233.258 miles	

EXPENDITURES (Approx.)

Pay Rolls	$12,500,000
Freight and Express	2,250,000
Lands and R/W	1,700,000
Materials, Equipment and Miscl.	8,150,000
	$24,600,000

MAXIMUM MEN EMPLOYED

May 11th to 20th, 1910, 3900 men.

MAXIMUM LIVE STOCK IN USE

September, 1911:	Owned by City	755
	Rented	600
	Total	1355

MAXIMUM MONTHLY EXPENDITURES.

May, 1910, $575,000.

ESTIMATED SALVAGE

Live stock, steam shovels, electrical and mechanical equipment, mining and concrete equipment, wagons, miscellaneous tools and equipment	$ 500,000
Power Plants and Transmission Lines	200,000
Cement Plant and Lands	550,000
	$1,250,000

SIPHON STEEL

Total tonnage, 15,000 tons.
Diameter of pipe, 7 feet 6 inches to 11 feet 6 inches.
Thickness of plate, 1⅛ inch to ¼ inch.

WORK STARTED

Elizabeth Tunnel, October, 1907.
Completed,—final, May, 1913.

PERSONNEL OF ORGANIZATION

BOARD OF CONSULTING ENGINEERS

Frederic P. Stearns of Boston, Mass.
John R. Freeman of Providence, R. I.
James D. Schuyler of Ocean Park, Cal.

BOARD OF PUBLIC WORKS

1907:
- James A. Anderson.
- Albert A. Hubbard.
- David K. Edwards.

1908-1912:
- Albert A. Hubbard.
- Lieut.-Gen. Adna R. Chaffee.
- W. M. Humphreys.

1913:
- Albert A. Hubbard.
- Edward Johnson.
- Lorin Handley.

ENGINEERING DEPARTMENT

Executive:
- Chief Engineer, Wm. Mulholland.
- Assistant Chief Engineer, J. B. Lippincott.
- Electrical Engineer, E. F. Scattergood.
- Mechanical Constructor, Roderick MacKay.

Field Engineers:
- Owens Valley, H. A. Van Norman.
- Olancha, O. W. Peterson.
- North Haiwee, W. P. Taylor.
- South Haiwee, Phil Wintz.
- Little Lake, Chas. H. Richards.
- Grapevine, F. J. Mills.
- Freeman, L. F. Mesmer.
- Jawbone-Mojave, A. C. Hansen.
- North Elizabeth, John Gray.
- South Elizabeth, W. C. Aston.
- Saugus, D. L. Reaburn.

THE CITY'S BENEFICIAL POLICY

In an arid region, it is always a serious matter to in any way interfere with the local water supply. It usually results in disappointments and contentions. Los Angeles, in its search for water selected a region where there would be a minimum of interference with existing human affairs. The necessity of the City required a large new water supply, and it sought this where diversion would do the least injury.

The policy adopted by the City was to obtain the water where it was cheapest and of least value, either present or prospective, and to put it where it would be of the greatest value to the greatest number. The City desired to build as large an Aqueduct as it could pay for, limited by the available water supply. Not only was the rapid growth of the City kept in mind, but also the possibility of developing her suburbs, and the fact that water was rapidly increasing in value and unappropriated scarcity throughout all California.

In 1903, a few months before the engineers of the U. S. Reclamation Service visited this field, some engineering promoters initiated investigations of the possibilities of power and irrigation development in the basin of Owens River. As far as known, their plans and financial connections were vague. No public announcements had been made of their intentions. They had posted water notices on Owens River at Long Valley and some other streams in Mono County, claiming large quantities of water, but had done no construction work. They complained that the public land withdrawals by the Secretary of the Interior for the U. S. Reclamation Service made in July, 1903, interfered with their plans, but at the time no notice was paid by the Department to their undertakings, which soon after were suspended. Their proposed use of the Long Valley reservoir and the main Owens River would have prevented the public development of this project either by the Government as an irrigation project or by the City of Los Angeles. A power plant was subsequently built by the California & Nevada Power Company on Bishop Creek, which is a tributary to Owens River, entering below Long Valley, and the power was taken by this company to the Nevada gold fields over rights of way that were granted by the Interior Department. No interference with this development has been attempted by the Federal Government or the City, nor was any ever intended. Their plans did not conflict with the projects that were contemplated either by the Reclamation Service or those subsequently built by the City.

At the time the Aqueduct was proposed, the valley had communication with San Francisco by means of a narrow gauge railroad running through Carson City and Reno to the Central Pacific, and to the south by a stage line of 120 miles in length, to Mojave on the Southern Pacific. Freight rates were excessive, and with the exception of the valuable minerals, there was little shipped out by rail. Cattle were driven out of the country on foot to the south.

The population of Inyo County, in which most of the agricultural land of the Valley lies, increased from 1,956 in the year 1870 to 4,377 in the year 1900. The proposed building of the Aqueduct became known to these people in 1905, yet in the year 1910 the population had increased to 6,974, or about sixty per cent. in the decade, and this growth has continued to date. In 1905 the assessed valuation of the entire county was $2,607,000.00, and in 1912 it had risen to $6,269,000.00, an increase of two hundred and forty per cent. According to the twelfth census of the United States, the irrigated area in 1899 was 41,026 acres, and in 1909, the thirteenth census states this irrigated area to be 65,163 acres, an increase of sixty per cent. for the decade. The area of the county is 10,019 square miles.

The City owns the Long Valley reservoir site below the 100-foot contour in Long Valley,

at an elevation of 6,650 feet at the dam site and above the point of diversion of the Aqueduct. A dam 160 feet high at this point will impound 340,980 acre feet of water and a dam 140 feet high would impound 260,000 acre feet. If it is found necessary or desirable, this Long Valley dam can be built. It will permit of the regulation of the flow of the Owens River to the capacity of the diversion canal and save flood waters, especially during wet years, which otherwise might pass into the lake and be lost by evaporation. By means of this regulation the value of the power plants that may be built in the gorge below the reservoir would be greatly enhanced. The purpose of this reservoir would be to hold over waters from years of excessive precipitation for years of drouth.

The waters diverted from Owens Valley to the City of Los Angeles are waters saved from loss and which have been of little beneficial use. The irrigation developments of Owens Valley are confined almost entirely to the northern half of the valley, and it is not expected that it will be necessary or desirable to interfere with them. The policy of the City is distinctly one of conserving the waste and loss of a great natural resource, and is in distinct contrast with the program which it would have been necessary to follow if the water had been obtained from Southern California sources, where diversions by the City would have resulted in the removal of water that was already being used in a most beneficial way. These conserved waters, brought from Owens Valley to Los Angeles, will be applied to the highest type of service. They will be distributed for the domestic necessities of half a million people. The suburban use of the water will result in the development of towns contiguous to Los Angeles, where the use will gradually change from agricultural to urban. The elevation at which this water will be diverted in Owens Valley is 3,812 feet above sea level and its delivery to the main pipe line leading to the City from San Fernando reservoir will be at an elevation of 1,135 feet. There will be available for power at Haiwee, San Francisquito and San Fernando, a total gross fall of 2,034 feet.

It is proposed to develop this power and convey it to the City. The program, therefore, was not only for the conservation of a wasted resource, but also for the application of this water to the highest type of beneficial use that is possible. The supply obtained will be adequate for the domestic necessities of a community of two million people, and the unit cost of the water is less than that which could be obtained from any other source.

The Los Angeles Aqueduct will not only supply the requirements of the present city, but will serve 135,000 acres additional, exclusive of that which may be saved from seepage waters if the main supply is properly placed. These lands when irrigated, including their improvements, should be enhanced in value $500.00 per acre, or a total of $67,500,000.00. Their crop values should easily amount to $100.00 per acre per annum, or half the cost of the Aqueduct each year. The benefit to the county from increased tax returns, on a one per cent. basis, would amount to two-thirds of a million per annum. Without any question every miner's inch of available water will be used.

Instead of being threatened with a failing water supply, Los Angeles now has one that is large and available, and twice as great as the aggregate total summer stream flow on a dry year for all the region from Santa Barbara to San Diego.

In all the transactions of the City in Owens Valley, it never condemned an acre of land, or a miner's inch of water. It paid the seller's price, without any recourse to compulsion, and it was offered much more land and water than it bought. The City has not exercised its right of exemption from taxes, but has always paid its taxes as a private owner would. To May, 1913, the City had purchased, under the act of Congress, government lands to the extent of 27,906 acres, and 97,023 acres of private lands, or a total holding in Owens Valley of 124,929 acres. The purchases made by the City were

mostly in the southerly portion of the valley, from what is known as Charlie's Butte to the Lake, including lands and canals. Some areas were bought in the northern half of the valley, but they were confined to the lower non-agricultural level lands, which are moist and from which artesian water or pumped water can be obtained. The canal water rights purchased aggregate about 11,000 inches. The irrigating season in this region begins May 1st, and extends until the middle of September. During the rest of the year irrigation is not practiced and the water is allowed to run in the river. In the southern half of the valley, in its low or central portions, the lands are largely artesian.

There is very little irrigation development in the southern portion of the valley, the farming being principally confined to the northern half. There has been no interference with this use of water in the northern portion of the valley near the towns of Bishop and Big Pine.

Since the purchase of these lands and the advent of the railroad into Owens Valley, the value of land and water have advanced greatly, and the City's operations have stimulated the prosperity of the people of Inyo County.

Appendix "A"

SYNOPSIS OF STUDY OF WATER RESOURCES IN OWENS VALLEY

MADE BY CHAS. H. LEE
FOR THE BUREAU OF THE LOS ANGELES AQUEDUCT

Owens Valley lies in east-central California and receives its relatively abundant water supply from precipitation on the eastern slope of the Sierra Nevada. It is an inclosed basin so lined by impervious rock formations that its ground waters have practically no subterranean outlet. Farming has been practiced here for more than 40 years, but because of the isolation of the valley the principal crops raised are alfalfa, corn, and grain, which can be consumed at home by live stock. The climate is arid, and irrigation is necessary for the production of crops. Canal systems deliver on the land water from Owens River and the tributary mountain streams. The area at present irrigated is limited by the natural flow of the streams in dry years during the period of maximum irrigation draft. The City of Los Angeles derives a municipal water supply from the surplus surface waters reaching the lower end of the valley and from the underground sources.

Investigations of these sources were carried on, under the supervision of William Mulholland, Chief Engineer of the Los Angeles Aqueduct, by Chas. H. Lee, whose observations extended over a period of three years—from June, 1908, to June, 1911. An exhaustive technical report of the study may be found in Water Supply Paper No. 294, U. S. Geological Survey.

The study is based on the fact that the porous valley fill of the Owens Valley occupies an impervious, undrained rock basin and that its void spaces constitute an immense underground storage reservoir. The principal source of supply of this reservoir is percolation from the precipitation upon its surface, from stream channels crossing its surface, and from irrigation. The only outlets for the water in Owens Valley as a whole are afforded by evaporation from water surfaces and damp soil, and by transpiration from vegetation. However, considering any isolated portion of the valley fill, the channel of Owens River provides an outlet for excess surface water which is not absorbed by the atmosphere. Owens Lake receives all such excess surface water from the river, and ultimately provides an outlet by evaporation from its expansive surface.

Owens Valley and its tributary mountain drainage exhibit within one hydrographic basin a very interesting combination of diverse climatic and resulting physiographic conditions. The higher levels of the Sierra Nevada receive abundant precipitation in the form of snow, whose annual variations are similar to those existing over the adjacent portion of its western slope. The remainder of Owens Valley has the characteristics of the desiccated valleys of the Great Basin, with the difference, however, that portions of its floor are covered with salt-grass meadows instead of desert sands, and the lowest depression is occupied by a large saline lake instead of a salt or alkali marsh. This difference is due to the relatively abundant water supply, and should this supply be suddenly cut off, the valley would soon acquire all the characteristics of the dried-up valleys or ancient lake basins of which Death Valley is a well-known type.

In shape the valley is long and narrow, with a northwest-southeast trend. Its length from the Mono divide to the south end of Owens Lake is 120 miles; its width from crest to crest of the confining mountain ranges varies from 40 miles at the north end to 25 miles at Owens Lake, its minimum width being 15 miles, between Bishop and Big Pine. The total area of the valley as far south as Olancha, with its tributary mountain drainage, is about 3,300 square miles, of which 1,200 square miles is occupied by desert mountains that yield practically no run-off; 536 square miles in the Sierra Nevada yield a large run-off; and 1,580 square miles consist of transition slopes, valley floor, and the surface of Owens Lake.

A secondary range, extending from a point a few miles north of the town of Bishop to the Mono divide, separates the upper valley into two parts, the western part being known as Long Valley. A depression called Round Valley lies between Owens Valley proper and Long Valley. Owens Valley extends as far south as the south end of Owens Lake, a distance of 80 miles, and its floor ranges in width from two to eight miles.

The elevation of the valley floor ranges from about 8,000 feet above sea level at the Mono divide to 3,570 feet at Owens Lake, the lowest point in the valley. The average slope in Long Valley is between 25 and 35 feet to the mile, and the elevation at its lower end is about 6,670 feet. From the end of Long Valley to the head of Owens Valley proper there is a drop of 2,200 feet in a distance of about 20 miles. Owens River has here cut a deep gorge through a lava sheet which extends across the valley. From the big bend in the river northeast of Bishop, at an elevation of about 4,100 feet, the slope to Owens Lake is fairly uniform and averages 7.5 feet to the mile. The average elevation of the outer borders of the valley along the eastern rim ranges from 4,000 feet near Owens Lake to 6,000 feet at the base of the White Mountains. The slopes that lie transverse to the valley are steep. The eastern face of the Sierra Nevada drops off at an average rate of 1,500 to 2,000 feet to the mile, and the slopes of the alluvial deposits flanking the range vary from 350 to 600 feet to the mile. The slopes of the western faces of the White and Inyo mountains range from 700 to 2,000 feet to the mile. The Valley floor has very light transverse slopes.

The elevation of the crest of the Sierra Navada averages 12,500 feet, though many peaks exceed this altitude, some of them by more than 1,500 feet. The lowest portion of the range is that extending from Mammoth Pass northward to the head of Glass Creek, the most northerly tributary of Owens River, and the highest is in the vicinity of Mount Whitney. The White and Inyo mountains have an average elevation of 10,000 feet, and northeast of Bishop they attain a height of over 13,000 feet.

The drainage system of the valley consists of a trunk stream, Owens River, fed by about 40 small tributaries entering at fairly regular intervals from the west. Water reaching the river from the east is derived from cloudbursts, which occur at long intervals, and is negligible in amount. The river discharges into Owens Lake, a saline body of water that has no outlet except by evaporation. The productive drainage areas of the tributary streams are the mountain canyons of the Sierra Nevada. The discharge from these canyons is perennial and represents true run-off, but in crossing the porous alluvial formation of the valley the streams lose much water, so that only a small part of this run-off reaches Owens River directly. This river provides a partial outlet for underground waters, however, and during low stages a large part of its flow is made up of seepage and spring waters.

The geologic structure of the Owens Valley region has interested geologists for many years. The following summary of facts concerning the structure is abstracted from a report by W. T. Lee. The valley is a V-shaped trough, whose bottom is filled to considerable depth with unconsolidated alluvial debris carried from the steep confining mountain faces by running water. The trough was probably formed by faulting along the parallel planes represented by the steep eastern faces of the Sierra Nevada and White mountains, accompanied by elevation of the eastern margins and westward tilting of the great crustal blocks represented by the ranges. There was probably also local faulting of the White Mountain block along its western face and settlement of the detached block, which at present lies buried beneath the valley fill. The western face of the trough is the granite escarpment of the Sierra Nevada, and the eastern face is composed of the sedimentary and igneous rocks of the White Mountains.

There are not a sufficient number of deep well borings to determine the character of the valley fill, but in general lake and river deposits occupy the lower portions of the valley and coarse mountain wash the upper edges, a zone of interbedded fine and coarse material lying between.

Inequalities in precipitation have resulted in marked inequality in the development of detrital cones along the bases of the parallel ranges. The cones at the base of the Sierra Nevada are connected with one another, forming a continuous slope, and are of immense size, rising to a maximum elevation of 2,000 feet above the river and extending out into the valley for 3 to 7 miles; those along the White Mountains are isolated and have maximum elevations of 1,000 feet and widths of half a mile to 2 miles.

The porous nature of the valley fill and the imperviousness of the rock basin in which it lies make ideal conditions for the storage of underground water.

Considering the valley fill as an immense underground storage reservoir, there are four

divisions, or ground-water regions, into which the reservoir is naturally divided by topographic and geologic features. These basins and their tributary drainage areas will be designated as the Long Valley region, the Bishop-Big Pine region, the Independence region, and the Owens Lake region. They are separated by transverse ranges of hills, which partly isolate sections of the valley fill and to a large extent cut off underflow from one region to another.

Because of the isolation of its valley fill, its simple topographic and geologic structure, its uniform run-off features of large contiguous areas, the small extent of its irrigation, its mild winter climate, and its accessibility, the Independence region was selected as the most favorable part of Owens Valley for a careful study of underground-water conditions. It has all the features of an underground reservoir of the arid region, developed with remarkable regularity and completeness, making it an ideal location for these investigations.

Precipitation has very unequal distribution over the Independence region, the average ranging from 3 or 4 inches a year at Owens River to 30 or 40 inches along the Sierra crest.

In the valley, the extreme range of departure for single seasons is from more than 350 per cent. to 20 per cent. of the normal, and over periods of 12 years the average may be 35 per cent. below the normal.

In the high mountain areas the range is from twice to one-third the normal, and periods of three years may occur when the average will be 30 per cent. below the normal.

The monthly distribution of precipitation is favorable to maximum percolation from the intermediate mountain and outwash slopes and to maximum snow storage in the mountains.

Stream discharge is at a minimum from September to April. The flow during these months is remarkably uniform and is entirely uninfluenced by the current storms, though 70 to 80 per cent. of the annual precipitation occurs between November 1, and March 31. The low-water flow is derived from springs and from the slow melting of the snow layer exposed to the earth's latent heat. Streams are usually frozen over by November, and as late as April they flow nearly to the mouths of the canyons in tunnels under the snow. Absolute minimum flows occur in December, in the absence of early snow; otherwise in January or February. Between April 1, and 20 air temperatures increase sufficiently to melt the snow at lower elevations and the streams begin to rise. There is an increase in air temperatures and stream flow from this date until the maximum flood crest is reached, some time between June 15, and July 15, depending on the amount of snow to be melted. Stream flow then decreases until some time in September, after which low water prevails. About 70 per cent. of the annual run-off of the streams from Oak Creek to Lone Pine Creek, inclusive, occurs during May, June, July and August. Goodale and Taboose creeks, however, are more regular in flow, only 56 per cent. of their run-off occurring during this period.

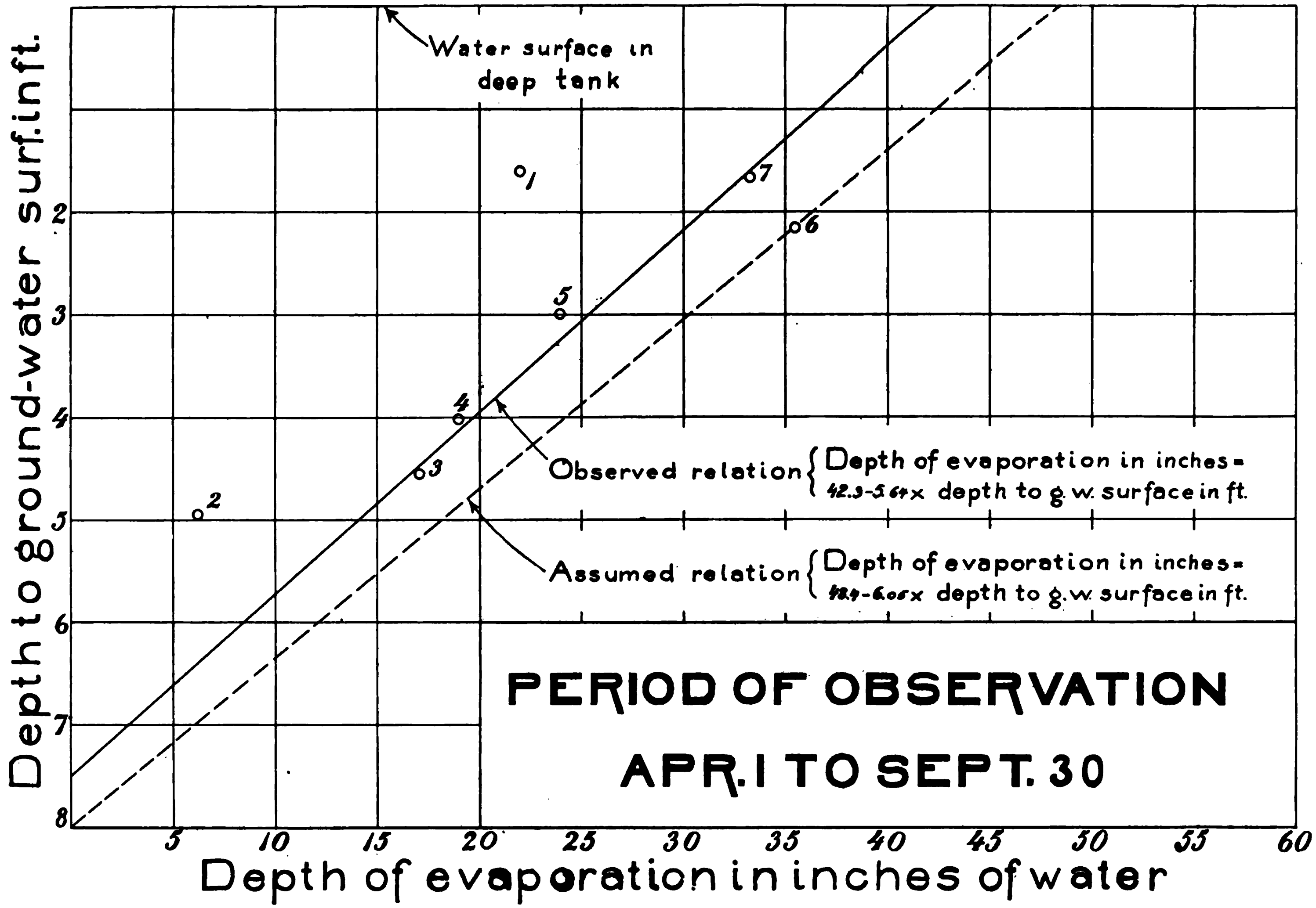
Owens River forms the eastern boundary of the Independence region for a distance of 29 miles, although the actual length of its channel is possibly 20 per cent. greater, owing to its sinuosity. It is the drainage outlet for the waste surface water of the region, including the run-off from the valley floor, the yield of springs, and a small portion of the run-off from high mountain drainage areas. In order to account for all escaping surface waters and determine the condition of the river channel with regard to seepage, daily measurements of river discharge were made near the north and south boundaries of the region, and measurements of discharge into and diversion from the river channel were made between these two points.

Surplus creek water reaches Owens River in appreciable quantities only during the high-water season. In the dry year 1908, there was no such discharge into the river; in the normal year 1910, there was about 3 second-feet during one month; and in the wet year 1909, the total discharge in June was 147 second-feet, in July 135 second-feet, and in August, 11 second-feet, which is equivalent to an average daily flow during the three months of 98 second-feet, or 12 per cent. of the total discharge from high mountain drainage areas during the run-off season 1908-9. Thus only a very small portion of the tributary mountain drainage ever reaches Owens River.

The total average surface run-off from various portions of the Independence region is 132 second-feet, of which 2 second-feet is derived from the valley floor and 130 second-feet from the high mountain drainage areas.

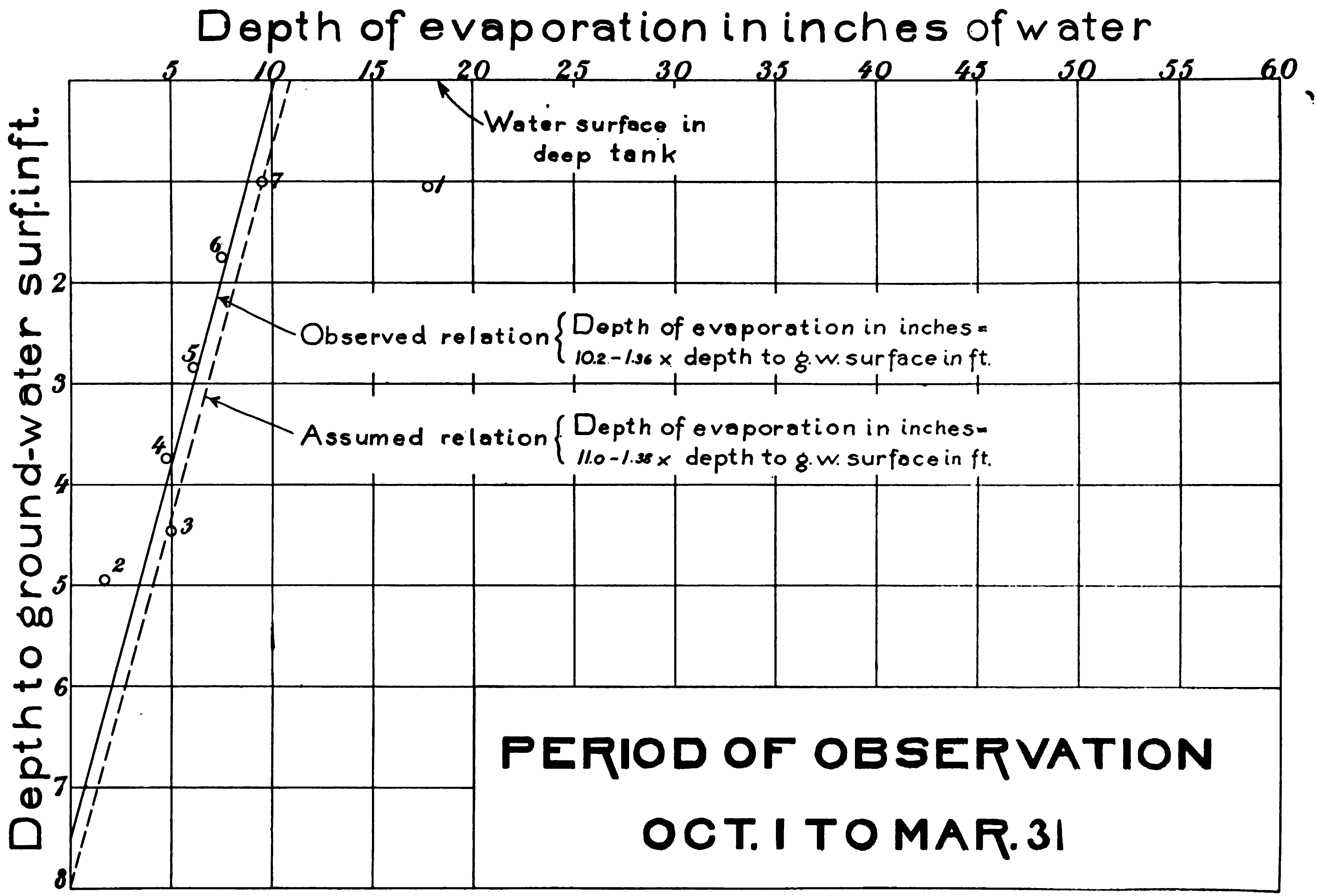
The portion of the run-off from high mountain areas reaching Owens River does not exceed 3 second-feet continuous flow.

A portion of the precipitation falling upon a drainage area returns to the atmosphere through evaporation. This not only occurs immediately after a storm, but also extends over a period whose duration depends on the character of the surface and underground storage of the drainage area. The latter consideration also largely determines the proportion of the total precipitation which will be lost by



RELATIONS BETWEEN EVAPORATION, SOIL, AND DEPTH TO GROUND WATER.

THE CONDITIONS IN OWENS VALLEY FOR THE TESTS HEREIN DESCRIBED BY MR. LEE WERE FOUND TO BE ALMOST IDEAL



CURVE SHOWING DEPTH OF EVAPORATION IN INDEPENDENCE REGION, OWENS VALLEY

evaporation from two drainage areas whose climatic conditions are similar. The process of evaporation is controlled by complicated and rapidly varying conditions, which scientific research has not yet satisfactorily analyzed and formulated. In general, however, it depends on the temperature and the quantity of moisture already in the immediately surrounding atmosphere. The latter factor depends not only on the amount of moisture in the air generally, but also on the action of wind in removing accumulated water vapor from above the evaporation surface. Warm arid regions have a greater annual loss through evaporation than those which are either cold and arid or warm and humid. Of the two controlling factors, probably temperature is the more important in determining the amount of evaporation, but over short periods wind may have a relatively greater influence. Owens Valley, although characterized by aridity, has a temperature somewhat modified by the proximity of the elevated Sierra Nevada, and evaporation in the valley is in general less than in the desert areas to the east and south, but greater than in the more humid San Joaquin Valley.

Evaporation may occur from water as it lies in the form of snow or ice, from free water surfaces, from bare ground, and indirectly from the soil by transpiration through vegetation. All these avenues for the passage of water as vapor from the earth's surface into the atmosphere are present in Owens Valley. An extensive snow-covered area exists in the higher mountains from December until June or July; mountain lakes and streams, Owens River, small lakes and flooded areas in the valley floor, and especially Owens Lake, furnish free water surfaces; and the whole ground surface at various times is in a moist condition favorable for the process of evaporation.

Water in the surface layers of the ground is subject to evaporation, either directly from the soil or through vegetation by the process of transpiration. It is available for evaporation in Owens Valley under two conditions—temporarily following a rainstorm or sudden thaw, and permanently within areas where the average depth to ground water does not exceed 8 feet. The total evaporation under the first condition is relatively unimportant because of the infrequency of storms and the small amount of precipitation, and no attempt was made to measure it. Under the second condition, however, evaporation is rather large, for not only is soil capillarity able to draw gravity water to the surface, but roots of vegetation, such as wild grass, penetrate the soil to ground water and become the channels by which a large amount of moisture is conveyed into the atmosphere. Evaporation from bare soil combined with transpiration is in fact the most important element entering into computations relating to ground water for this region.

Owens Valley is an ideal location for carrying on such experiments. In the first place, the source of water available for evaporation may be kept under the complete control of the observer as regards amount and rate of supply. Storms are rare and the total precipitation small, so that little uncertainty exists from this cause regarding the amount of percolation from precipitation upon the surface of a body of isolated soil. Second, the method by which the surface soils of the valley floor are kept moist can be artificially reproduced on a small scale with only a slight departure from natural conditions. The source of supply for soil moisture is a permanent ground-water surface from which water is drawn by capillary forces. This ground water is replenished by percolation from the precipitation and surface water of the intermediate mountain and outwash slopes, which seeps laterally toward the valley floor and lies beneath it under hydrostatic pressure sufficient to maintain a permanent ground-water surface. Similar pressure can be reproduced in the bottom layer of an isolated body of soil, and capillary forces can be depended upon to raise moisture to the surface. Finally, the large annual depth of evaporation makes possible a more accurate determination of its amount than in a less arid region. Experiments carried on under these conditions have been very satisfactory.

The rate of evaporation from soil depends on the temperature of the air and soil, the quantity of moisture already in the immediately surrounding atmosphere, the amount of moisture in the surface layers of the soil, and the character of the vegetation and other soil covering. The first two of these factors have the same effect on soil evaporation as on that from free water surface—higher air and soil temperatures result in increased evaporation, as does also drier atmosphere or increased movement of wind. The third factor is directly proportional to the rate of evaporation, because the loss of moisture occurs from soil grains at or very near the surface. The amount of moisture in the soil available for evaporation thus depends upon the character of the soil as regards capillarity and depth to ground-water surface. For example, in a coarse sandy or gravelly soil "gravity water" will be drawn to

the surface through the capillary spaces from depths not exceeding four feet, while in a fine sandy or clayey soil water will be drawn from depths as great as eight feet. The last factor, the extent and character of vegetation, affects the evaporation rate both through the activity of transpiration and the effect upon capillarity. Plant roots are continually absorbing water from the soil; this water passes off into the atmosphere through the leaves, and the evaporation losses from soil are greatly increased thereby. The roots of native salt grass will penetrate to a depth of eight feet in search of water. A further effect of the growth of vegetation is to increase the vertical capillary flow of moisture through soil by way of the many tubes filled with the rotted fiber of dead roots. These tubes are the result of years of growth, and penetrate the soil in all directions above the ground-water surface.

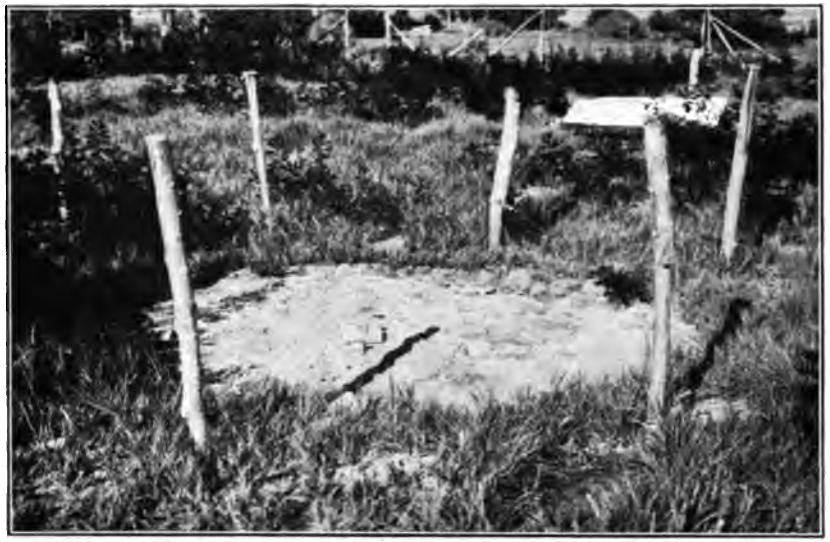
The purpose of the experiments was to obtain data sufficiently complete to compute the total volume of water annually lost by evaporation and transpiration from the valley floor. This involved making observations under the various local conditions which affect soil evaporation. The plan was to reproduce natural conditions in isolated bodies of typical soil and determine the evaporation therefrom for varying climatic conditions, depths to ground water, soils, and vegetation.

The experimental equipment consists of two galvanized iron tanks 6½ feet in depth connected at the bottom by an 18-foot length of galvanized pipe. The smaller tank is 2 feet 4 3/16 inches in diameter and is furnished with a tight-fitting cover. The larger tank is 7 feet 5¼ inches in diameter, and has a system of branching perforated pipes at the bottom connected with the pipe from the smaller tank. These two tanks and all connections are watertight, and water poured into the smaller or reservoir tank passes into the larger or soil tank and escapes through the perforations. These two tanks were placed in excavations of proper size to receive them, the soil tank was filled with the excavated soil, and the reservoir tank was filled with water. A six-inch layer of screened gravel, too coarse to enter the 1/16 inch perforations was laid in the bottom of the soil tank to insure an uninterrupted and well-distributed feeding of water from the reservoir tank into the superimposed soil. As soon as the material became saturated and capillary action established to the surface, the water level in the soil was brought to the desired depth and kept there by supplying water to the reservoir tank in measured quantities. Volumetric measurements of water poured into or withdrawn from the reservoir tanks were made with an ordinary gallon measure. Accumulation or depletion of the supply in the reservoir tank was determined volumetrically by measuring the depth of water with a steel tape. The volume passing out of the reservoir tank during a given period represents the total evaporation from the soil tank during that period.

The position of the ground-water surface in the soil tank was determined by measuring its depth below the ground surface in auger holes of two-inch diameter bored in the soil to a proper depth. Measurements were made from a fixed point with a steel tape weighted at the end and chalked before each observation. Three holes were placed in each tank half-way between the center and rim on radii 120° apart. For reasons noted below, some of the tanks were provided with six holes placed on radii 60° apart. The holes were not bored deep enough to reach the bottom layer of coarse gravel, and the water level in them represented the ground-water surface in the surrounding soil. An average of the observations made at a given time was assumed to represent the general depth to ground water for the tank at that time. The tendency for the sides of the holes to cave in and the bottom to fill with sand was controlled by casing them with two-inch galvanized sheet-iron pipe generously perforated with 1/16 inch holes. These pipes were so driven that the top was just flush with the ground surface, and they were closed at the top with wooden plugs. In some of the tanks it was found impossible to bring the ground-water surface to the desired level with the available hydrostatic pressure from the reservoir tanks, and two-inch holes were bored between the observation holes to the saturated gravel layer. Water usually rose in these holes to the same height as in the reservoir tank, and by seeping laterally into the soil built up the ground water surface. It was found difficult to keep these holes open to the gravel, however, and the water level in most of them eventually represented the ground-water surface.

Three tank sets were installed in the open valley floor east of Independence in February, 1909. The surface of soil tank No. 1 was bare sand; Nos. 2 and 3 were laid with salt-grass sod. The initial plan formulated for tank sets Nos. 1 and 3 was to hold the ground-water level at various depths below the ground surface for periods of a few weeks during the summer while the climatic conditions were

Soil Tank No. 1 in Operation



Soil Tank No. 3 in Operation

Sierra Nevada from the Vicinity of Artesian Well No. 2

Artesian Well No. 2

constant, in order to obtain, in a short time and with few tanks, trustworthy results of a general nature. The movement of the water surface from one level to another consumed so much time, however, that winter approached before the experiments on the lower levels were reached, and furthermore, there was no accurate method of determining the volume of evaporated water represented by the differences in depth. The experience of the first year's work with these tanks showed the necessity of maintaining a fixed ground-water level during a complete cycle of climatic changes. In soil tank No. 2 it was at first proposed to hold the ground-water level at or near the ground surface, but so great was the rate of summer evaporation that this plan was found to be impracticable with the equipment available. To remedy the defect, the hydrostatic pressure from the reservoir tank was increased by soldering to it a three-foot extension, but this extension could not be used until late in the season. This experience suggested the desirability of placing the reservoir tanks above the soil tanks and of increasing the size of the feed pipe from three-quarter to one inch.

In order to test this plan, four additional tank sets were installed in January, 1910.* The reservoir-tank outlets were placed about 1.7 feet above the soil-tank inlets, and one-inch pipe was used throughout. The new soil tanks were laid with salt-grass sod, which grew fairly well. In tank set No. 1 the depth of water in the reservoir tank was held at six feet to maintain a uniform hydrostatic pressure in the soil tank, and thus reproduced natural conditions. No attempt was made in this set to control ground-water fluctuations artificially. In tank sets Nos. 2 to 7, water was supplied to reservoir tanks in quantities such that the depths to ground water were respectively 5 feet, 4.5 feet, 4 feet, 3 feet, 2 feet, and 1 foot. Observations were carried on continuously in the seven tanks for one year in order to study the effect of the ordinary range of climatic conditions. By this plan sufficiently complete data were obtained to make computations of evaporation loss from the valley floor.

The annual depth of evaporation from the several soil tanks exhibited a consistent decrease with increase of depth to ground water and varied from 43.1 inches for No. 7 to 7.9 inches for No. 2. The depth of summer evaporation varied from 77 to 83 per cent. of the annual in the several tanks and averaged 79 per cent. The month of maximum evaporation is August, and minimum evaporation occurs most commonly in February. Observations of depth to water in transition zones between meadow and desert land indicate that soil evaporation ceases at a depth of 8 feet.

A considerable portion of the water evaporating from soil is absorbed by plant roots and carried upward through the stem and into the foliage, whence it escapes in the process of transpiration. This process continues as long as the plant has life, but is most active during the growing period. Transpiration differs in different species of plants and even in the same species when existing under different conditions of light, atmospheric pressure, soil texture, and available moisture in the soil. King's experiments indicate that humidity does not affect transpiration. For a species growing in a definite locality, light and available soil moisture are the controlling factors.

The process of transpiration and respiration in plants is similar to the breathing of animals. Both plants and animals inhale air and exhale from the respiratory organs large quantities of water. The lungs of animals are intended primarily to provide a means for the entrance of oxygen into the body and for the escape of carbon dioxide, but they can not perform their functions unless the interior lining of the air cells is kept moist. Similarly the breathing surface of a plant must be kept moist, and, as a protection from too rapid evaporation, this surface is within the plant structure, principally in the foliage. Plant leaves are inclosed in a relatively impervious skin or epidermis, in which are small breathing pores or stomata, which automatically open or close, depending on the needs of the plant for a greater or less amount of air. When exposed to light, the food-manufacturing processes of a green plant are stimulated and require a continually changing volume of air in contact with the breathing surface. The stomata open proportionally to the light intensity. Should the water supply in contact with the roots be insufficient, the breathing surface may become dry, and when that happens the stomata automatically close until the proper amount of air is admitted for the plant to do its work under the new conditions. The stomata therefore controls the amount and rate of loss of water from plants by transpiration.

There is a marked diurnal periodicity in the rate of transpiration which investigators are led to believe is largely the result of varying intensity of light.

*See Plate No. 23. Cross Section and Location of Evaporation Tanks—in map pocket.

No measurements of transpiration that have been made under conditions similar as regards altitude and aridity to those in Owens Valley are available. It is unnecessary in the present study to know separately the transpiration from wild grasses and evaporation from bare soil, because the area of the latter is relatively small. The experiments on soil evaporation were therefore planned to give the combined loss from these two causes. It is desirable, however, to know the amount of transpiration from field crops, to aid in computing the amount of percolation from irrigation. Observations for such crops were confined to alfalfa.

The method of measurement was based on the assumption that the rate of loss of water from freshly cut plants would correspond closely with that before cutting. The plants were rapidly cut from a measured area, weighed, and spread out on paper to cover the same area as before cutting. At short intervals they were reweighed until there was no further appreciable loss. No noticeable wilting occurred during the first 15 minutes, and the rate of loss during this period was used as a basis for calculations.

Four average samples were cut, at 8:45, 9:15, and 10:30 a. m., and 2:02 p. m. The initial weights of the samples were 3 pounds 15½ ounces, 4 pounds 7 ounces, 5 pounds 5 ounces, and 4 pounds 7 ounces.

The rapid decrease in the rate of loss is very noticeable. The rates of transpiration at 8:45, 9:15, and 10:30 a. m., and 2:02 p. m., expressed as percentages of the average rate for 24 hours, are respectively 128, 141, 177, and 197, an average of 161 per cent. If a similar relation is assumed, the average loss in a 24-hour day from the four alfalfa samples would be 366 ounces to the square yard of field area, or 0.49 inch in depth. This figure appears rather large at first glance, for the rate of evaporation for that day from the pan in Owens River was 0.30 inch, and that from the shallow pan in the soil was 0.38 inch. The results obtained by German investigators indicate the loss from sod during the growing season to be 92 per cent. greater than from water surface, and that from cereals to be 73 per cent. greater. Furthermore, the humidity of the air, after passing over an alfalfa field, is very noticeably greater than after crossing a body of water. The result obtained in the experiment here described is therefore within reason.

The growing season for alfalfa in the vicinity of Independence is marked by an entire absence of cloudiness. It extends from about April 15 to September 30, during which time three crops mature, the yield being about 5 tons of dry matter to the acre. The samples used for the experiments were almost ready for the second cutting.

On the assumption that the average area of transpiring surface during the entire growing season was 50 per cent. of that on the day of the experiment, the total loss of water during the season would amount to 41 inches, or 3.43 feet in depth. With a production of dry hay amounting to 5 tons to the acre there would therefore be one pound of dry matter for every 93.5 pounds of water lost by transpiration. These results, though apparently large, are regarded as approximately correct.

The depth of evaporation from snow which falls upon the high mountain areas is approximately 7.7 inches annually.

The depth of annual evaporation from the surface of water near Independence in a pan floating in Owens River is 67 inches, in a pan set in soil approximately 85 inches, and in a deep tank set in soil 69 inches. The percentages of these totals occurring between April 1st and September 30th, are 75, 77, and 71, respectively. The depth of summer evaporation averages 79 per cent. of the annual for the various depths. The depth of combined soil evaporation and transpiration in irrigation near Independence is about half the depth of water applied.

Water reaching the surface of porous unsaturated ground has a tendency to pass downward to the surface of saturation. This process, known as percolation, is very important in connection with the occurrence of underground water.

The four sources of ground water are percolation from direct precipitation, from stream flow, from irrigation, and from flood water in the valley floor.

The first of these yields about 44 second-feet, of which 61 per cent. is from the intermediate mountain slopes, 30 per cent. from the outwash slopes, and 9 per cent. from the valley floor. Percolation from streams yields about 79 second-feet, of which 68 per cent. is above Government gaging stations, and 32 per cent. below. Irrigation yields 18 second-feet and flood waters in the valley floor 9 second-feet.

The total ground water is therefore 150 second-feet, of which probably 75 per cent. reaches the deeper strata of the valley fill.

The aggregate voids in the porous alluvial material filling the bottom of the closed rock basin of the Independence region form a great

Evaporation Pan on Owens River near Citrus Bridge

Evaporation Pan in Soil

Deep Water Evaporation Tank

Soil Evaporation Tank Set, Before Installation

underground storage reservoir, whose source of supply is percolation from water occurring upon the surface of the valley fill. There can be found in nature few better opportunities than this for studying the occurrence and behavior of water in such a reservoir. The well-defined sources of supply which it is practicable to measure, the simplicity of the geologic structure, the definite bounds within which ground water is confined, and the ideal climatic conditions for measuring the natural outlets by evaporation are unique when combined as in the region under investigation.

The alluvial material, which forms the valley fill, varies in size from large bowlders to fine clay, and in arrangement from a thorough mixture of all sizes to layers of well-assorted gravel, sand, and clay.

Two cross sections of the valley showing the probable geologic structure of the region were constructed along the Thibaut and Independence sections. The topography for these sections was obtained from the Geological Survey's map of the Mount Whitney quadrangle, and the character of surface material was determined by field inspection. The exposed slopes of bedrock on either side of the valley were joined beneath the valley floor, and the arrangement of the material filling the basin thus formed was represented according to the best available knowledge, the strata of fine material being indicated by solid black. The greatest depth of alluvial filling in the Independence section measures 2,500 feet on the diagram and in the Thibaut section 1,800 feet. Two of the aqueduct wells near the Independence section reached depths of 500 feet in alluvial material, and a well being drilled by the Southern Pacific Co. opposite the Alabama Hills at Lone Pine station has reached a depth of 800 feet, entirely in fine sand. There is no reason to suppose that the gravel filling near Independence is less than 2,000 feet in depth.

The amount of void space, or porosity, of a body of alluvial material of this type is variously estimated by different authorities at 20 to 35 per cent. of the total volume. The presence of very coarse gravel and bowlders would reduce the porosity, and for the valley fill as a whole 25 per cent. is probably correct.

An interesting feature of the valley fill of the Independence region is its total storage capacity for water. Its surface, as represented by the outwash slopes and valley floor, has an area of 230 square miles. On the assumption of an average depth of 1,000 feet of saturated alluvial debris beneath this area and a porosity of 25 per cent., the void space filled with water is 10.9 cubic miles, or 37,000,000 acre-feet. A portion of this water is capillary and not available for recovery from the ground. If one-fifth the total volume is assumed to be gravity water, there would be approximately 7,000,000 acre-feet, which could be extracted from the underground reservoir, or a continuous flow of 3,200 second-feet for three years.

There is a very striking relation between vegetation and depth to ground water. On the outwash slopes the vegetation consists of various stunted desert shrubs. In approaching the valley floor at about the 20-foot depth contour, sagebrush (Artemisia) begins to predominate and has a luxuriant growth as far east as the 12-foot contour, where it is replaced by greasewood, rabbit brush, and coarse bunch grass. In the vicinity of the 8-foot contour salt grass (Distichlis spicata) begins to appear, and farther east, near and within the area inclosed by the 4-foot contour, it grows luxuriantly. Within the 3-foot contour fresh-water grasses thrive where there is sufficient surface water to leach out and carry away most of the alkali, but the salt grass grows well even where the soil is alkaline. In various portions of the valley floor, rabbit brush and greasewood are found where the average depth to ground water is 4 feet or more, but grass predominates east of the 8-foot contour. In areas where the alkali is excessive there is practically no vegetation. In general, grass does not grow where the depth to ground water exceeds 8 feet, so the 8-foot contour tends to coincide with boundaries between meadow and desert lands.

Ground-water fluctuations within the valley floor consist primarily of the regular annual rise and fall produced by variation in the rate of evaporation. This is indicated by actual observations extending over three years and confirmed by the persistency of various perennial plant species. Hence there must be overflow of ground water from the valley fill of the region in general equal to inflow by percolation.

The amount of water used in irrigating 3,011 acres under cultivation in the region is about 72 second-feet continuous flow for six months, which is equivalent to a depth of 8.6 feet over the whole area. The depth of transpiration from alfalfa during the irrigating season has been computed as 3.43 feet, or 40 per cent. of the total volume used. There is also a small loss through evaporation from the soil during and immediately after irrigations, say 0.85 foot, or 10 per cent. of the total. The total loss by evaporation from the soil and transpiration from irrigated areas is therefore 4.3 feet in depth, or 18 second-feet continuous flow.

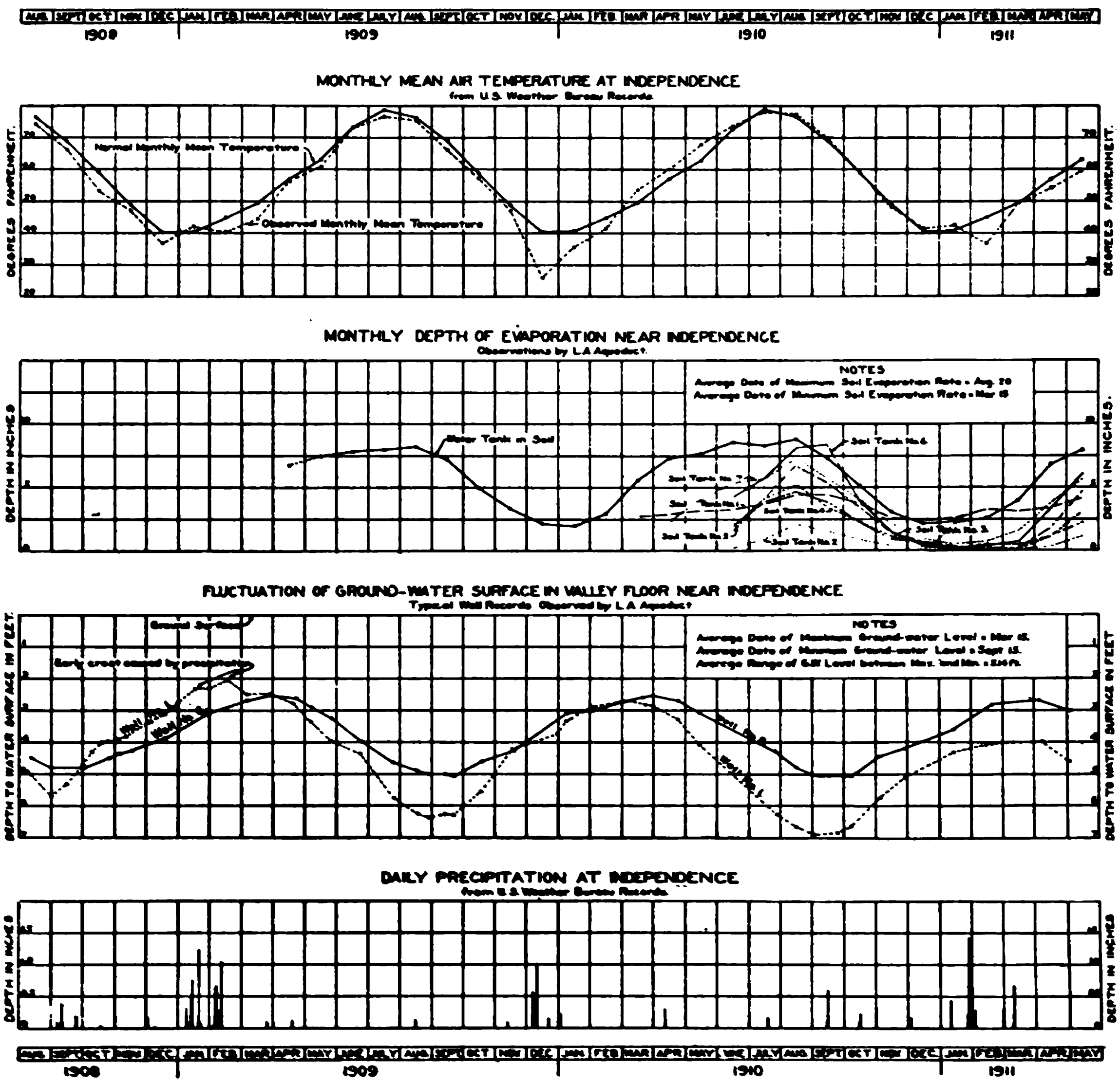


DIAGRAM 11.- TEMPERATURE, EVAPORATION FROM SOIL, PRECIPITATION AND FLUCTUATION OF GROUND-WATER SURFACE IN VALLEY FLOOR NEAR INDEPENDENCE.

The volume annually evaporating from the whole non-irrigated area is equivalent to a continuous flow for the year of 93 second-feet. The total volume evaporating from this area, as computed by use of the assumed equations, is 114 second-feet. The first of these quantities is believed to be too small, and it is possible that the second is too large.

The water of Blackrock and Hines springs and of the small springs along the upper edge of the valley floor spreads out in many shallow lake basins before reaching Owens River. The loss by evaporation from the surface of these lakes is large. Estimates based on the area of water surface exposed and the evaporation from water in the shallow pan in soil indicate that about 50 per cent. of the flow of these springs thus escapes into the atmosphere. As the combined flow is 31 second-feet, the loss by evaporation from free water surface is 15 second-feet. The remaining portion which does not flow into Owens River percolates into the soil and escapes by evaporation from the soil and transpiration.

Two springs deriving their waters from percolation discharge directly into Owens River; these are Upper and Lower Seeley springs. Their combined average flow is 11 second-feet. In addition the Blackrock Springs discharge an average of 7 second-feet into the river during the months November to March, inclusive, which is equivalent to a continuous flow of 3 second-feet. The total discharge into the river from springs is therefore 14 second-feet.

The total ground-water yield is thus greater than 140 second-feet and equal to or less than 161 second-feet. In the opinion of the writer, experiments extending over the calendar year 1911 would establish the value as 155 second-feet.

The structure of the valley fill is favorable for the underground storage of water.

The ground-water surface lies within a few feet of the ground surface throughout the valley floor. West of the spring belt it rises with a slope of about 90 feet to the mile, which is less than the slope of the ground surface.

The total ground-water yield is 155 second-feet, distributed as follows: Soil evaporation and transpiration from grass and alkali lands of valley floor, between 93 and 114 second-feet; soil evaporation and transpiration from irrigated land, 18 second-feet; evaporation from spring flow, 15 second-feet; discharge of springs into Owens River, 14 second-feet. Data indicate the equality of ground-water supply and yield.

Appendix "B"

REPORT UPON THE SANITARY QUALITY OF THE OWENS RIVER WATER SUPPLY DELIVERED TO CONSUMERS IN LOS ANGELES THROUGH THE LOS ANGELES AQUEDUCT SYSTEM

BY CHARLES GILMAN HYDE
SANITARY AND HYDRAULIC ENGINEER

A REVIEW OF
THE CASES OF HART AND FROST vs. THE CITY OF LOS ANGELES,
BEING A CONSIDERATION OF
THE SANITARY QUALITY OF THE OWENS RIVER WATER SUPPLY DELIVERED
TO CONSUMERS IN LOS ANGELES
THROUGH THE LOS ANGELES AQUEDUCT SYSTEM
By
CHARLES GILMAN HYDE
Sanitary and Hydraulic Engineer,
July 1, 1915.

LEGAL FEATURES OF CASES.

Antagonism to Aqueduct Project

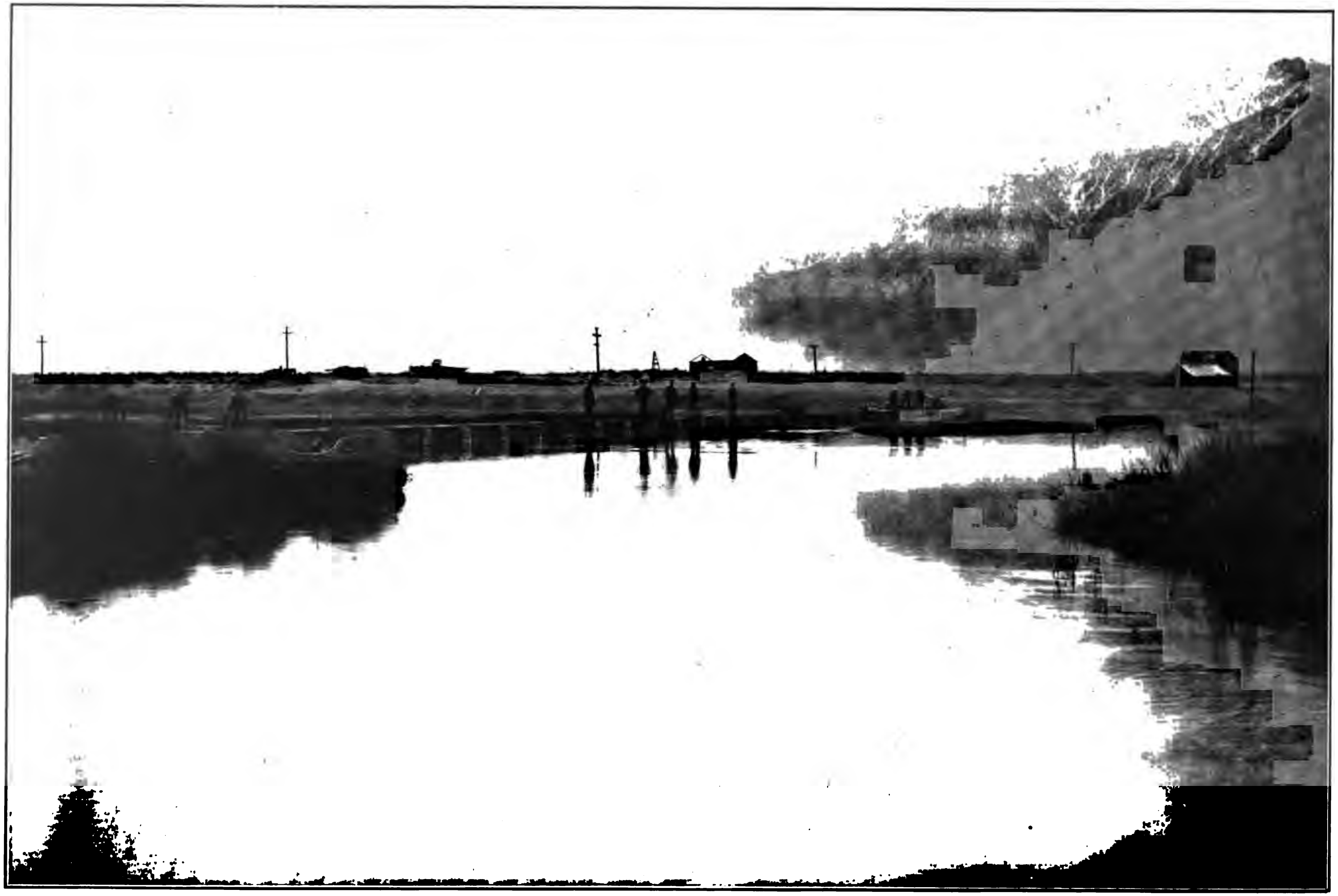
The conception of a great system of water supply from Owens River for the people of Los Angeles was nothing less than an inspiration. Its construction has required faith, loyalty, brains and engineering ability of the highest order. Its consummation spells for the citizens of Los Angeles a degree of success and a brilliancy of future which could in no other way have been so perfectly vouchsafed.

Yet from the beginning all sorts of selfish interests have antagonized the development of this magnificent project. These interests have for the most part waged a battle from the ambush. They have used the knife in the dark. They have not permitted their identity to be disclosed. Mere dummies posing as citizens jealous of the welfare of the people or as public spirited engineers have served as screens for the "malefactors of great wealth" who would have been able to profit if this scheme of water supply could have been throttled or if spurious claims to water in the Owens River drainage basin could have been foisted upon the city at great cost. Fortunately, the construction of the works was not thereby halted. The engineers and attorneys for the city and the real citizenship which had the best interests of the city at heart did not falter. They carried the enterprise through according to the original program of capital outlay, capacity of works and time schedule.

It remained for one final, but again futile, effort to be made to destroy the project at or about the time when, the aqueduct and reservoirs having been sufficiently completed, the water was finally brought to the threshold of the City and turned into the distribution system. This attempt to undermine or destroy the efficacy of the Aqueduct system took the form of injunction proceedings to restrain the further use of water from Owens River.

Motions for Injunction Against Use of Owens River Water

The first suit, including a motion for a preliminary injunction, was filed in the Superior Court of Los Angeles County on or about August 15, 1914, by Henry A. Hart. Mr. Hart was



WHERE OWENS RIVER IS DIVERTED INTO THE AQUEDUCT

the leader of the mal-odorous majority of the People's Aqueduct Investigation Board, so-called, whose work and report are too well remembered to require extended mention here. It is sufficient to state that, after having been in existence for six months and having spent $16,535.48 in "investigating," they were unable to find any evidence of graft or incompetence in the prosecution of the aqueduct project. They were willing to go on record, however, as being certain, on the basis of their intimate knowledge of human nature, that were they to be continued in office for a sufficiently longer period with sufficiently larger sums to expend, tangible evidences of graft and incompetence would be forthcoming.

It was shortly discovered that no sufficient cause of action existed in Hart's case because he was not a resident within the territory supplied with aqueduct water, which was a principal ground of complaint. A second suit was therefore filed in behalf of Edgar M. Frost, who seemed to be willing to serve as a dummy plaintiff and who conveniently lived in the district which was being supplied with water from Owens River. Furthermore, among other activities, Frost was employed as a detective in the office of attorney for plaintiff during the period covered by the suit.

The suits were brought by Mr. Ingle Carpenter, as attorney. The names of the clients in whose interests he served, Mr. Carpenter has not yet seen fit to divulge, nor did they appear during the hearing of the case.

As a self-styled servant of the people Mr. Carpenter made a trip into the Owens Valley region in June, 1914. In July he employed Dr. Ethel Leonard as a sanitary expert and accompanied her on a six days' inspection trip over the watershed. A few samples for bacteriological and chemical examination, and a few photographs, were taken at this time. Upon her return to Los Angeles, Dr. Leonard prepared a report of her sanitary investigations. This was shortly printed and, consistently enough, was clothed in yellow covers. It was spread broadcast throughout the city and country "wherever it could do the most harm."

The original motion for a preliminary injunction was supported by seven affidavits filed by H. A. Hart as plaintiff, Ingle Carpenter as attorney, Dr. Ethel Leonard as sanitary expert, Ralph Leonard as assistant, Dr. A. F. Wagner as chemist, H. R. Fosbinder as veterinarian, and G. L. Hazlett as searcher of records. These affidavits were variously dated between August 7th and 13th. The order to show cause why the injunction should not be granted was signed by Judge Lewis R. Works as Presiding Judge of the Superior Court, under date of August 15th, and required the defendants in the action, the City of Los Angeles and the individual members of the Board of Public Service Commissioners, to appear in Court on August 26th. The representatives of the parties appeared, but the hearing on the motion for a preliminary injunction was postponed on account of the absence of Dr. Ethel Leonard, who departed for Chicago immediately after making her report, above noted. Judge Works then decided that no preliminary injunction should be issued and that the case should be set down for an early trial.

A second suit was filed on behalf of Edgar M. Frost on October 5, 1914. The summons was dated October 5th, and required that the defendants appear and answer within ten days thereafter.

Affidavit of Dr. Ethel Leonard

The principal affidavit in support of the motion of H. A. Hart looking to a preliminary injunction, restraining the further use of Owens River water through the Aqueduct system, was that of Dr. Leonard. This paper was almost identical with the printed report above mentioned. Something of the profound technical ability of this expert for the plaintiff, and something of the animus actuating her work, may be inferred from the following statements in the affidavit in question:

"Although cultures"—of Horton's creek water—"made by the State Hygienic laboratory showed the presence of typhoid bacilli, the source of infection and virulence of the organisms could not be accounted for." No samples from this source were ever examined by the State Hygienic Laboratory. Moreover, neither this laboratory nor any other reputable laboratory attempts to differentiate B. typhosus in routine work and but few authentic isolations of this germ have ever been made from potable waters.

"Physical conditions"—at the north end of Haiwee Reservoir—"demonstrate beyond question that even bacteria cannot develop in such polluted water."

"The course of these creeks"—mountain streams emptying into Long Valley—"lies through the marshes of Long Valley which contain enumerable"—(innumerable)—"dead cattle." The testimony in the case showed that only two or three carcasses of varying ages were discovered in an area fully 20 square miles in extent.

"Owing to the large number of germs and contamination by organic matter found in practically all of the samples, it was deemed inadvisable and impractical to attempt to segregate the specific pathogenic bacteria." The real reason should lie in the limitations of bacteriological procedure, not in the causes named.

"The inoculation of the Owens River water from its source to the intake with pathogenic and saprophytic bacteria must so alter its chemical condition that the continued use by the residents of Los Angeles for human consumption and domestic use, even with boiling precautions, must necessarily result in severe gastro-intestinal diseases. Other diseases resulting from disturbed metabolism will undoubtedly attack anyone who continuously drinks this water."

"My investigation shows that any use of Owens River water is absolutely impossible from a sanitary standpoint."

"Plate cultures all developed 72 hours before colonies were counted." "Cultures were kept as near as possible at a uniform temperature, 37° C." The period of incubation employed by Dr. Leonard was three times as great as American standard methods dictate.

Complaint of Edgar M. Frost

The complaint of Edgar M. Frost, upon which the second suit was based, made the following principal allegations:

(1) That the City of Los Angeles, a municipal corporation, through the Board of Public Service Commissioners, who have immediate charge of the water works system, furnishes as a portion of its supply, the water from Owens River through the Los Angeles Aqueduct.

(2) That the plaintiff is furnished with water from this source which is alleged to be polluted in various designated ways above the point of intake and is therefore unhealthful to consumers in the City of Los Angeles.

(3) That certain streams such as Cottonwood Creek are unpolluted and sufficient for present purposes and that the supply can be extended by the use of other protected creeks.

(4) That no permit had been obtained from the State Board of Health.

(5) That the supply derived from Los Angeles River has hitherto been unpolluted and healthful, but now has become polluted by the turning of Owens River water into the distribution system.

(6) That various chemical and bacteriological analyses made in behalf of the plaintiff on samples collected from the system as far down as San Fernando Valley show the water to be polluted and therefore dangerous and unhealthful to consumers in the City of Los Angeles and to the plaintiff.

During the trial, the falsity of every statement named above, except (1), (4), and the first part of (5), was demonstrated beyond peradventure. With respect to item (4) Judge Works declared that the statute which appears to require that a permit to operate the works must be secured from the State Board of Health is either unconstitutional or else was covered by charter provisions since the Los Angeles City charter confers on the City the right and power both to acquire and to operate and control a water works system.

Hearing Before Judge Works

The Hart and Frost cases were assigned by Judge Works to himself. After several postponements, all at the instance of Ingle Carpenter, attorney for the plaintiffs, the trial of both cases was begun on January 5th, it being agreed that the cases be tried together. The trial continued with few interruptions until the decision was rendered on March 19th. The hearing consumed 40 court days. The transcript embraced some 6,312 pages and possibly 1,250,000 words.

In its relation to the best interests and the general welfare of the people, the capital outlay involved and the number of trained experts employed, this litigation represents one of the most important cases yet heard in the United States dealing wholly with a water supply problem. From the standpoint of the significance and complexity of the sanitary principles involved, as well as from the standpoint of its general importance, this litigation is outranked by the famous Chicago Drainage Canal Case (State of Missouri vs. the State of Illinois and the Sanitary District of Chicago, 1900-1906), which comprehended problems of sewage disposal as well as of water supply. In volume of testimony and the number of trained experts employed this litigation is to be compared with the Jersey City Water Supply Case (City of Jersey City vs. Jersey City Water Supply Company, 1904-1908).

Throughout the trial Judge Works proved himself to be most fair. He was extremely generous in the admission of testimony from both sides. He was tireless in his attention to every detail and angle of the case. Because of his extremely judicial temperament and his clear grasp of the problems as presented to him, his decision must be considered to be practically faultless and impregnable.

Intake of the Aqueduct—(Figures Left to Right, Engineers Lippincott, Mulholland, MacKay and Edward Johnson of Board of Public Works)

The case was most ably conducted for the city by Mr. W. B. Mathews, Special Counsel to the Board of Public Service Commissioners, assisted by Mr. Wm. B. Himrod, Deputy City Attorney. The experts testifying in behalf of the City were Wm. Mulholland, Chief Engineer of the Board of Public Service Commissioners, and Dr. Stanley Black, Dr. Walter V. Brem, Charles Gilman Hyde, Dr. Edwin O. Jordan, Charles H. Lee, E. O. Slater, and Carl Wilson. Testimony on certain engineering and operative features of the Aqueduct system was given by Messrs. Van Norman, Shuey and Jones of the Aqueduct staff.

The case for the plaintiffs was conducted by Mr. Ingle Carpenter, attorney. The experts testifying in behalf of the plaintiffs were Dr. Ethel Leonard and Dr. Ernest A. Victors. The testimony on behalf of plaintiffs on certain engineering features of the case was given by Messrs. R. E. Child, H. E. Linden, and Cyril Williams.

BRIEF DESCRIPTION OF AQUEDUCT SYSTEM

Sources of Supply

The principal sources of supply of water to the Aqueduct system are, or will be:—(1) Owens River, taken about half-way between the villages of Big Pine and Independence, and about 257 miles via the Aqueduct works from Los Angeles; (2) Black Rock Springs, tributary to the line of open aqueduct above Haiwee Reservoir about three miles below the intake on Owens River; (3) Cottonwood Creek and some thirteen other smaller creeks tributary to the line of open aqueduct; (4) A large volume of artesian water to be taken in the future, when necessary, from wells sunk along the west side of the open aqueduct in the Independence region.

It is considered to be unnecessary to discuss herein the yield of these various sources of supply. It may be stated that the works have been so designed that any or all of these sources may be drawn upon at will. Only a few wells have as yet been developed. The flow from these is regularly taken into the Aqueduct. The line of open aqueduct north of Haiwee Reservoir is completely controllable by gates so that as much or as little water may be diverted from Owens River and the tributary creeks as may be desired, limited, of course, to their respective yields.

Elements of System of Works

In order that the contentions of the City and the findings of the Court as respects the quality of water finally delivered to consumers in Los Angeles may be understood, it is necessary that a fairly comprehensive idea be had concerning the system of works comprised in the Aqueduct project, especially with reference to their capacity and dimensions. The system may be roughly outlined as follows:

(1). An intake on Owens River about 15 miles north of Independence, the county seat of Inyo County. The drainage area tributary to this point is estimated to be about 2,740 square miles. The elevation is 3,814.8 feet. The intake is so designed that as much or as little water as is desired may be diverted from the River.

(2) A line of open aqueduct 60.8 miles in length from the intake on Owens River to the north end of Haiwee Reservoir. The upper or northerly portion of this aqueduct, comprising about 23.72 miles, is an unlined ditch; the remainder or southerly portion is lined with concrete. Throughout its entire length, this stretch of open aqueduct is protected by a substantial barbed wire fence. All bridge crossings are properly enclosed. The carrying capacity of this section of the aqueduct is 580 million gallons per day. The rate of flow is estimated to vary from an average of about 1.1 feet per second, with a draft of 26 million gallons per day, to 2.8 feet per second when the draft reaches 272 million gallons. This section of the Aqueduct is provided with various diversion and regulating gates whereby the amount and character of the water entering it or flowing therein may be controlled.

(3) Haïwee Reservoir with high water elevation of 3760 feet. This reservoir consists virtually of three great elongated basins connected by narrow straits. Taken as a whole it is sinuous. The banks are bold, steep, and deeply incised by ancient erosion. The immediate watershed is small, uninhabited, practically rainless, a desert and almost without runoff. The only waters reaching this reservoir in significant amount must arrive through the open aqueduct discharging into the north end. The intake by which the water must leave the reservoir is located at the extreme southerly end. Practically all water entering the reservoir must traverse its entire length of 7.25 miles before it can escape through the intake into the line of aqueduct below. The reservoir has an average width of about 2400 feet and an average depth of 30 feet. The area of water surface at the high water line is 2,100 acres or

nearly 3.3 square miles. It has been created by two hydraulic-fill dams, one at either end. The maximum depth of water at the north dam or inlet end is 28 feet; that at the south dam or intake end is 64 feet. The capacity of this great reservoir, when filled to the high water line, is 20,800 million gallons.

This reservoir is indeed unique among the storage reservoirs of the world. There is believed to be no other reservoir in existence on a similar or anything like a similar scale of magnitude where the inflow is absolutely controllable because of the fact that it is not filled from its own watershed. The danger of short-circuiting when maintained with a reasonable depth of water is therefore absolutely eliminated.

(4) About 135.5 miles of aqueduct from the south end of Haiwee Reservoir to Fairmont Reservoir. For about 2 miles immediately below Haiwee Reservoir the Aqueduct consists of an open concrete-lined ditch. The remainder of the distance is comprised of concrete-lined covered aqueduct, concrete-lined tunnels and riveted steel inverted siphons. The carrying capacity of this section is 272 million gallons per 24 hours, and the velocity of flow varies from an average of about 2.7 feet per second, with a draft of 26 million gallons per day, to about 5.3 feet per second when the draft becomes 272 million gallons daily.

(5) Fairmont Reservoir, with a proposed high-water elevation, when completed, of 3,025 feet. This reservoir is being created by an hydraulic-fill dam which has not yet been raised to the ultimate height proposed. The present storage capacity is about 277 million gallons. The distance from inlet to outlet is about 0.4 mile. When completed the reservoir capacity will be 1940 million gallons. This basin will serve as a huge forebay for the San Francisquito power plant.

(6) About 17.6 miles of concrete-lined and covered aqueduct, concrete-lined tunnels and riveted steel pipe lines from Fairmont Reservoir to Dry Canyon Reservoir. At the present time a portion of these works are under construction, and ever since the plant has been in service the water has been allowed to flow for a distance of about 9 miles through the San Francisquito Canyon to the location of the tunnel below the power house. (Since the above was written, the tunnels in San Francisquito Canyon have been completed and the natural stream bed of the canyon is only used for a distance of about one and one-half miles in an inaccessible gorge in hard granite rock, which imparts no objectionable character to the water.) The capacity of the conduits in this section is about 650 million gallons per 24 hours. The rate of flow is estimated to vary from a general average of 2.4 feet per second, with a daily draft of 26 million gallons, to 4.8 feet per second when the average draft becomes 272 million gallons per day.

(7) Dry Canyon Reservoir with high water elevation of 1505 feet. This reservoir has been created by an hydraulic-fill dam. The storage capacity is 430 million gallons. The distance from inlet to outlet is about 0.7 mile. This basin will serve as an equalizing reservoir to compensate for variations in draft on the part of the power plant in San Francisquito Canyon and on the part of the City.

(8) About 11.5 miles of covered aqueduct, lined tunnels and riveted steel pipe lines from Dry Canyon Reservoir to the Cascades, thence about 1.6 miles of open lined ditch to the inlets of the San Fernando Reservoirs. The capacity of the conduits in this section is 272 million gallons per 24 hours. The rate of flow is estimated to vary from an average of about 2.7 feet per second, with a daily draft of 26 million gallons, to about 5.4 feet per second when the Aqueduct is delivering at its full rated capacity.

(9) San Fernando Reservoir No. 1 with a proposed high water elevation of 1265 feet, a length between inlet and intake of 0.7 mile, and a capacity of 4,900 million gallons. This reservoir has not yet been constructed.

(10) San Fernando Reservoir No. 2 with a proposed high water elevation of 1135 feet, a length between inlet and intake of 1.4 miles, and a capacity of 7,500 million gallons. This reservoir is being created by the erection of a high hydraulic-fill dam. This reservoir will be by-passed and will not form a component part of the works, as now proposed, delivering water into the present distribution system of Los Angeles.

(11) About 12.8 miles of concrete-lined tunnel and riveted steel pipe line from San Fernando Reservoir No. 1 to the inlet of Upper Franklin Reservoir. The capacity of this conduit is 97 million gallons daily. The rate of flow therein is estimated to vary from about 1.0 foot per second, with a draft of 26 million gallons per day, to about 7.4 feet per second with a daily draft equal to the capacity of the conduit.

(12) Upper Franklin Reservoir with high water elevation of 850 feet, a length between inlet and intake of 0.25 mile and a capacity of 42 million gallons. This basin has been created by an hydraulic-fill dam to serve as a distributing reservoir for the City.

HAIWEE RESERVOIR, LOOKING SOUTH TOWARD DAM FROM ABOUT CENTER OF LOWER BASIN

(13) About 1.1 miles of riveted steel conduit from the intake of Upper Franklin Reservoir to the inlet of Lower Franklin Reservoir. This pipe line has a carrying capacity of 39 million gallons per 24 hours. The velocity therein will vary from about 3.1 feet per second, with a draft of 26 million gallons per day, to about 8.6 feet per second when flowing at its rated capacity.

(14) Lower Franklin Reservoir with a proposed high water elevation of 575 feet, a length from inlet to intake of 0.63 mile and a capacity of 360 million gallons. This reservoir is now under construction. It is being created by an hydraulic-fill dam. Like Upper Franklin Reservoir this basin will serve as a distributing reservoir for the City.

(15) A main riveted steel pipe line about 7.0 miles in length connecting Lower Franklin Reservoir with the district in Los Angeles supplied from the aqueduct system. This line has a rated carrying capacity of 26 million gallons per day. When delivering this volume of water the velocity therein is about 3.1 feet per second. It can deliver 40 million gallons per day, at which rate the velocity in the pipe line would require to be 5.3 feet per second.

Storage Capacity and Storage Period

The total storage capacity of the reservoirs now built and building, through which water supplied to consumers in Los Angeles must pass on its way from the source of supply in Owens Valley, is 23,570 million gallons. From the data just presented, it is possible to calculate the time factor in the conduits and reservoirs of the system with the exception of the storage period in Haiwee Reservoir. If maintained half full of water this will never be less than 38 days with an ultimate development of works represented by 272 million gallons per day. With the use of water at the rate of 26 million gallons daily, as at present, the storage period at half capacity is 402 days. The storage periods with the reservoir maintained full of water would be double the figures just given.

Other reservoirs are possible and are proposed in the ultimate system of works. With these in service the storage periods would be vastly prolonged.

THE SOURCE OF SUPPLY FROM A SANITARY STANDPOINT

General Considerations

The fundamental factor determining the degree of significant pollution of any given source of water supply is the extent to which it does or may receive the foecal wastes from human beings. Man himself is the chief agent of infection of mankind. Animal infection is relatively unimportant and especially so when matters of water supply and the diseases which are water borne are considered. A moderate amount of organic matter in water, in the absence of pathogenic bacteria, must be considered as entirely harmless and without significance. Long human experience with waters charged to varying degrees with the organic matter in question has demonstrated beyond peradventure the fact just stated.

Theoretically the germs of one serious animal disease may be carried by water and may cause sickness among human beings. This disease is anthrax. Throughout the hearing of the case the counsel for the plaintiffs attempted to make a strong point of this feature since anthrax to a limited extent has occurred among cattle in the Owens Valley. The annals of hygiene, however, fail to record one single case of human anthrax which can be attributed to the drinking of an infected water supply.

It remains therefore to examine the conditions prevailing within the drainage basin of the aqueduct supply to determine the extent to which human and perhaps animal foecal wastes do or may enter the streams and cause their contamination. Furthermore, all of the conditions of self-purification of these waters must be examined to determine the likelihood of the survival of any pathogenic bacteria, should such enter the supply above Haiwee Reservoir, until the water is delivered to consumers in Los Angeles.

Between the inlet of Haiwee Reservoir and the distribution system in Los Angeles, a distance of 196.2 miles via the Aqueduct works, involving a chain of at least five reservoirs and perhaps six, there is not one permanent source of contamination of the Aqueduct water. The only temporary source of possible contamination is the course of San Francisquito Canyon for a distance of nine miles (*), wherein the Aqueduct waters are or have been allowed to flow during the period required for the construction of certain tunnels, fore-bay, penstocks, power-house and tail works in this section. This section is practically uninhabited except for the Aqueduct construction camps near the power house site. The canyon is traversed by a county road, which sustains some small amount of travel.

(*) See item 6, page 300.

Area and Extent of Watershed

The total drainage area tributary to Owens River above the intake of the Aqueduct is estimated to be 2,740 square miles. That tributary to the inlet of Haiwee Reservoir is about 3,350 square miles, including 500 square miles in the watershed of Cottonwood Creek above the line of the Aqueduct. The drainage area directly tributary to Haiwee Reservoir is perhaps 60 square miles. In general the westerly portion of the drainage basin comprising the easterly slopes of the Sierra Nevada Mountains is the only part from which there is any considerable run-off. The easterly portion of the drainage basin is comprised of the dry, arid westerly slopes of the White and Inyo Mountains.

Resident Population and Its Disposition in the Drainage Basin

The total population resident in the drainage basin of Owens River above Haiwee Reservoir is estimated to be about 4,600 at the present time. Roughly speaking the bulk of this population is grouped in four districts, as follows: in Round Valley, in and around Bishop, in and around Big Pine, and in and around Independence. There are perhaps 1150 dwellings within the drainage basin and of these fully 650 are scattered and are outside of the villages just named. From figures presented in the last Federal census reports it is estimated that there are not more than 350 farm or ranch houses in this entire area of 3,350 square miles in question. It will be seen that the average density of population is but 1.4 persons per square mile.

There is scarcely a large impounding reservoir in the United States on whose watershed the population is so sparse as that tributary to the Los Angeles Aqueduct at Haiwee Reservoir. The average density of population on 77 reservoir watersheds in Massachusetts, a state of notably excellent and safe water supplies, is 132 per square mile. The density of population on the reservoir drainage basins of Boston, Worcester, Fall River, New Bedford and Brockton, Mass., and Rochester and Syracuse, New York, ranges from 21 to 210 times as great as that upon the watershed tributary to Haiwee Reservoir. In none of these cases is the water purified and made safe in any other way than by storage. In none of these cases is a reservoir filled by any other way than from its own watershed under conditions, especially as regards flood, which are not controllable.

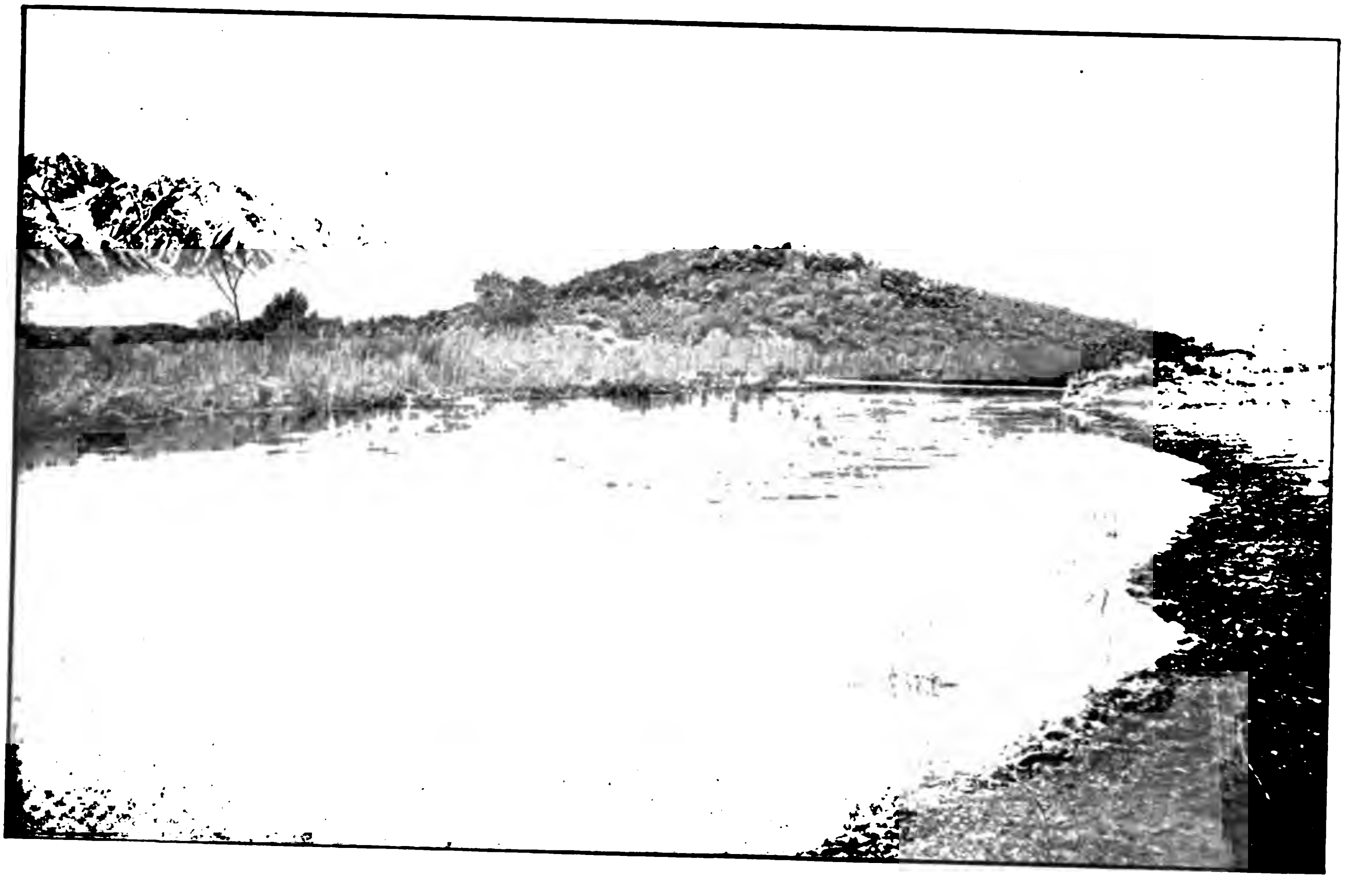
There is but one incorporated place on the drainage area above Haiwee Reservoir. This is the little City of Bishop, estimated to have a population of 1500 at present. There are but two unincorporated hamlets or villages in the drainage area. These are Big Pine, having a population of perhaps 300, and Independence, the County seat, having a population of 200.

From the best statistics available it appears that the animal (domestic) population of the area is 35,700, of which 40% are cattle and 38% sheep and goats. On the average there is one domestic animal to every 60 acres in the drainage area.

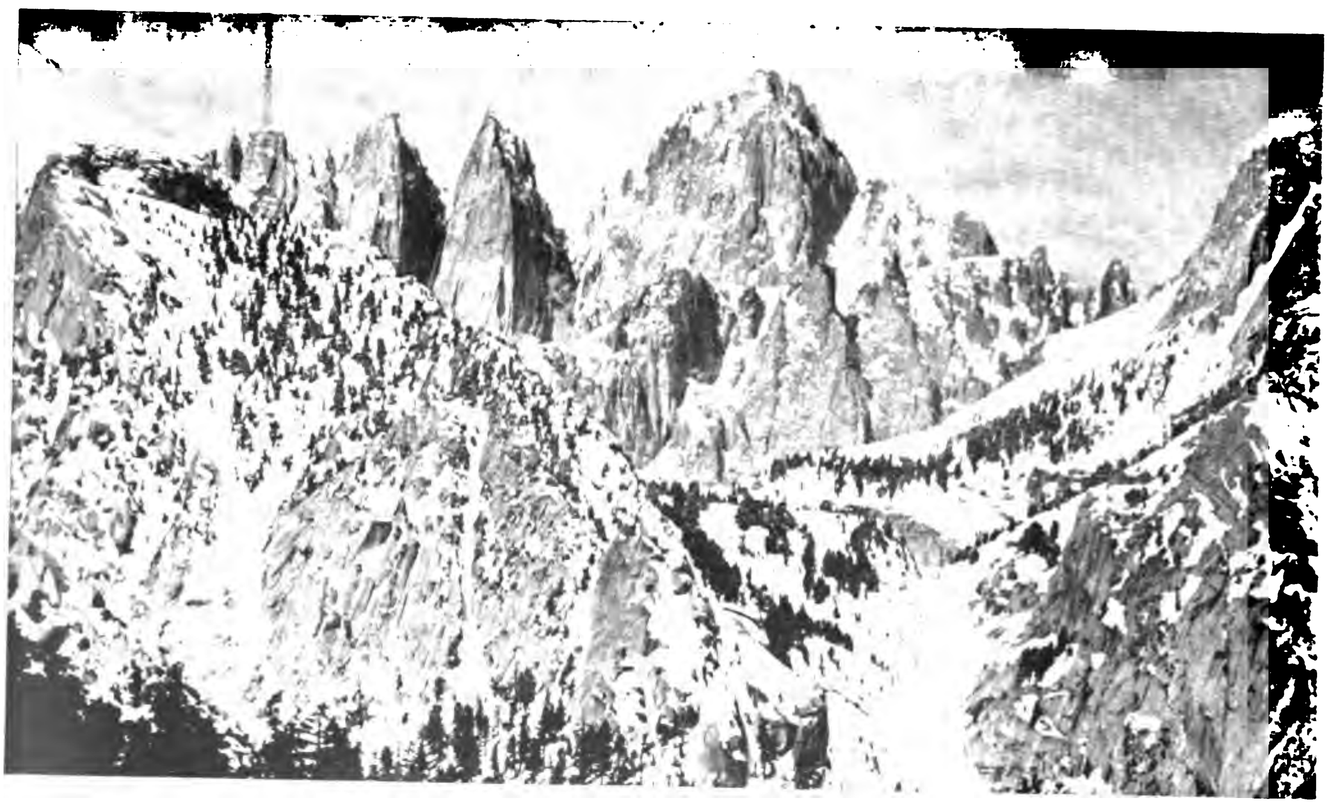
Nature and Extent of Pollution

The City of Bishop is provided with a sewerage system serving approximately two-thirds of the population or perhaps 1,000 persons On account of the high ground water in this district the sewers have been underdrained. The underdrains for some unaccountable reason have been arranged to discharge into the sanitary sewers at the manholes. In consequence the flow is relatively very large and the sewage is correspondingly very weak. The present total daily flow of sewage is perhaps 500,000 gallons, or 500 gallons per capital connected with the sewers. The sewage is treated in a septic tank of the Cameron type, and the effluent is discharged through ditches upon land. For the most part it disappears through seepage into the coarse gravelly soil, but at times at least a portion of it overflows lands to the southeast of the septic tank and enters a slough which, after a long course with many interruptions in the shape of ponds, lagoons and marshes, reaches Owens River or Big Pine Canal, according to conditions. If received into Big Pine Canal, which is believed generally to be the case, it is carried far to the south, where it disappears entirely through seepage and does not enter Owens River or any of its direct tributaries. Just east of the location of the septic tank there is a low ridge of sandy land which mechanical analyses of properly collected samples show to be perfectly adapted to sewage disposal by intermittent sand filtration. The sewage of Bishop could unquestionably be disposed of in a most effective and innocuous way upon filter beds properly constructed and operated upon the site in question.

Five hundred persons in the town of Bishop and the remaining 3,100 persons elsewhere in the drainage area are provided with privies. It seemed to be possible to find but one privy in all this number, namely 900, which discharged its contents directly into any natural stream or irrigation canal. The exception noted was at once suppressed. It is doubtful



OWENS RIVER AT CHARLEY'S BUTTE



CLOSE VIEW OF SUMMIT CRAGS OF MT. WHITNEY. ELEVATION 14,501 FEET

if there is another equivalent number of inhabitants in rural America who have so completely refrained, as have the people in Owens Valley, from directly polluting the local streams and irrigating waters. In a very few instances investigation showed that privies were in existence at distances as small as from 4 to 6 feet of controllable water courses, such as irrigation ditches, but the vast majority, say fully 95%, were located at substantial distances from such water courses.

It has become the custom in Owens Valley to build stock corrals immediately adjacent to natural streams or with irrigation ditches passing through them. In a very few of these corrals it is possible that considerable amounts of manure may be washed by very heavy rains or high water into the streams. A careful study of the conditions has shown that in the majority of cases the water courses passing through the corrals are irrigation ditches and are controllable with respect to the volume of water flowing therein. In very many instances these ditches are above the general level of the corrals.

It can be stated positively that the conditions within the drainage area tributary to the Los Angeles Aqueduct above Haiwee Reservoir are unusually good, for rural communities, with respect to the amount of human or animal contamination of the water supply. Furthermore, the conditions are such that, with a minimum expenditure of time and money, through sanitary inspection, the conditions can be made thoroughly satisfactory.

THE AQUEDUCT SYSTEM FROM A SANITARY STANDPOINT

Longevity of Pathogenic Bacteria

It is apparent that if, under all circumstances, the length of time required for any water supply to pass from the last possible source of pollution to the point of distribution and use is greater than the longevity of pathogenic organisms under the environmental conditions which obtain, then such a supply must become safe. The result is the same as that which would be secured by other processes, as by filtration or chemical disinfection. Herein lies the fundamental principle of the purification of water supplies by storage.

The pathogenic bacteria are, as a class, used only to the rich warm juices of the animal body. If, perchance, they are cast into the relatively cold environment of a body of water they are at once confronted with conditions which are unusual and untoward. They cannot long survive.

The period representing the viability of pathogenic bacteria causing the water-borne diseases constituted one of the chief features of contention between the parties during the hearing of the cases in question. The evidence seemed to be overwhelming (and even the experts for the plaintiff could not but acquiesce if the opinions of the authorities which they themselves cited, may be relied upon) that the life of such organisms, even of the resistant minority, so-called, must be very brief. All recent experiments and investigations, conducted under modern laboratory procedure and having due regard to the conditions actually prevailing in nature, demonstrate that the great mass of typhoid bacilli introduced into an ordinary surface water supply die out in a very few days, say two or three, and that all are destroyed within, say, two weeks. A storage period of three weeks or a month would surely be sufficient to insure the destruction of all bacteria causing the group of diseases in question. Of these diseases typhoid fever is, in America, by very far the most important. In the tropics cholera is the most dreadful water-borne disease. All available evidence goes to show that the longevity of the cholera vibrio is substantially less than that of the typhoid bacillus. Bacteria causing bacillary dysentery are probably but little, if any, longer lived in water supplies than are the typhoid bacilli.

Agencies of Self-Purification

There are many inter-related agencies or factors tending to separate and destroy any pathogenic bacteria which may enter a stored water supply. Those which seem to be the principal factors may be enumerated as follows: (1) devitalization, the general result of an unfavorable environment; (2) dilution or separation, reducing the number of organisms per unit of volume; (3) equalization or the tendency to produce uniformity in numbers and conditions; (4) sedimentation, both in the presence of particles of considerable subsiding value and without; (5) the inhibiting and destructive action of sunlight; (6) the inhibiting and devitalizing effect of relatively low temperatures; (7) low or different and always unsuitable food supply; (8) the inhibiting and destructive effect of the toxic products of saprophytic bacteria; (9) the ill-defined action of osmosis. The net result of the action and inter-action of these several factors may be summed up in the term "general unfavorable

environment." In considering the efficiency of storage in the destruction of pathogenic bacteria, it is only necessary to insure that the time factor is sufficient; in other words, that the time elapsing be so great that any disease-producing bacteria discharged from the human organism will be destroyed before those same germs can be re-ingested by other human beings. The expression "those same germs" is used advisedly since all the evidence at hand shows that under the environmental conditions herein considered, the pathogenic bacteria in question cannot multiply or produce their kind. The problem, therefore, becomes one of destroying certain bacteria which are extremely sensitive to environmental conditions and which cannot long survive those which are untoward.

Reservoirs as Sanitary Safeguards and Purifying Agencies

A chain is only as strong as the weakest link determines: a reservoir, as respects the destruction of pathogenic bacteria, is only so safe as the minimum time factor represents. Most storage reservoirs are filled directly by the tributary streams from their own immediate watersheds. Very many of these are subject to "short-circuiting" by floods, which pass rapidly through them, or by waters, contributed from portions of their watersheds, which are concentrated close to their outlets. Thus, one of the most notable reservoirs employed for domestic water supply purposes in California has a capacity represented by fully 500 days of the safe yield of the catchment area, yet during maxima floods there has been wasted over its spillway in two days' time a volume of water equivalent to the entire reservoir prism. Again, one of the lakes repeatedly referred to in the testimony in behalf of the plaintiff as having been short-circuited by wind action, has 5% of its total drainage area tributary in the immediate vicinity of its outlet where the water works intake was located. About 14% of the drainage area was tributary at a point three miles from the intake in question, the lake being eleven miles in length. Approximately 22% of the watershed area was tributary to the shores of the lake through very large numbers of small water courses. The lake shores are populated by large numbers of summer residents and the entire drainage basin is comprised in a farming community and probably supports no less than forty persons per square mile, representing nearly thirty times the average density of population on the drainage basin tributary to the Los Angeles Aqueduct.

The possible effects of wind in tending to induce short-circuiting in reservoirs received much attention on the part of the witnesses for the plaintiff. It naturally was attempted to make as much of this matter as possible. The conditions of shape, depth and topography of the surrounding country at Haiwee Reservoir did not, however, lend themselves readily to such arguments as these witnesses were able to offer. Indeed, such experiments and observations as could be made at the reservoir with reference to this general matter seemed to weaken rather than to support the theories advanced.

Notwithstanding the limitations to which storage reservoirs in general are subject, the available information shows that they are in general among the greatest of sanitary safeguards for water supplies; and supplies derived therefrom, are, on the average, fully as safe if not actually safer than the effluents of modern water purification plants of various accepted types. Of the fifty cities in the United States having in 1910 populations of 100,000 or over, eight have water supplies which are protected and purified by storage alone, and eleven others either have safe ground water suplies or else are sterilizing their supplies, in some cases subsequently to filtration. The average typhoid fever death rate per 100,000 for the five-year period 1909-1913 for the first group of eight cities was 8.0, while that for the second group of eleven cities was 13.2.

The typhoid fever death rate in forty-three cities and towns in Massachusetts whose water supplies are purified by storage alone was only 8.08 per 100,000 for the three-year period 1910-1912. The average rate for the entire state during the same period was 9.5.

Nature and Capacities of Reservoirs in Aqueduct System

The general nature and capacities of the several reservoirs now built or building in connection with the Los Angeles Aqueduct project have been briefly discussed in the foregoing pages. It is, of course, patent that if reservoirs are empty they become no better than stream beds and the time factor becomes little or nothing. In estimating upon the time factor which will apply to the Aqueduct works, it has been necessary to assume some storage below which the reservoirs will never be drawn. A careful study of the whole matter has led to the conclusion that Haiwee Reser-

Aqueduct Water Falling from Elizabeth Tunnel Into San Francisquito Canyon

voir could and should be maintained at a stage representing never less than one-half capacity and that the remaining reservoirs in the chain at stages never less than two-thirds capacity. Such assumptions require that the water resources of the system be sufficient, dependable and available upon demand. That such will be the case has been demonstrated by a long series of stream measurements and underground water investigations.

Haiwee Reservoir has in its bottom certain depressions of considerable size which are below the lowest intake level. It, therefore, can never be drained completely by gravity even if this were desired. All of the other reservoirs of the system, excepting perhaps San Fernando Reservoir No. 2, must from the very nature of their purpose, be maintained at all times as full as possible.

As stated above Haiwee Reservoir is notable from the fact that it is so very large and yet is not filled from its own watershed, but only through a 60-mile line of aqueduct in which the flow is absolutely under control at all times. The maximum rate of filling, with no draft upon the reservoir—an impossible condition—cannot be more than 650 million gallons per day, equivalent to only one-thirty-second of the total capacity of this huge reservoir. There are, of course, reservoirs fed directly from their own drainage basins which do not fill and cannot be filled except in a prolonged interval. However, very few, if any, of these reservoirs receive their entire supply at one end and draw it from the other and few are as well calculated to insure total displacement in so doing as is Haiwee Reservoir. A usual case is the one cited on page 308. Another well-known illustration is the Boonton Reservoir, which, although fully two miles in length, receives its supply almost entirely at a point only 3,900 feet distant from the intake of the water works which is located at one end of the dam creating the storage basin.

The catchment areas of all of the other reservoirs in the Aqueduct system are also small and uninhabited and the supply of water received therefrom is safe and entirely suitable for domestic purposes.

Assuming that Haiwee Reservoir is maintained at least one-half full of water and the other reservoirs of the system (exclusive of San Fernando Reservoir No. 2) at least two-thirds full, the total minimum storage period in the system at various stages of draft or development will be as follows:

Draft per Day.	Days in Storage and Transit.
26 million gallons	468*
136 million gallons	122
272 million gallons	65

*San Fernando Reservoir No. 1 and Lower Franklin Reservoir not in use: San Fernando Reservoir No. 2 by-passed.

By these figures it will be seen that, even with ultimate development when the draft reaches an average of 272 million gallons per day, the minimum period required for the water to pass from the inlet of Haiwee Reservoir to consumers in Los Angeles, under the assumed conditions of stage, would be 65 days. This interval is so great that there will be not the slightest likelihood of the survival of any pathogenic bacteria which might by chance enter the supply at the source. Under the draft conditions existing at the time of the hearing of the cases in question, the time interval was fully 468 days. With the works developed to one-half their ultimate capacity, the time factor in question will be fully 122 days under the conditions of stage assumed.

Yield of Source as Related to Time Factor

Very careful series of long-time gaugings and various studies of water resources have shown that the yield of surface water from Owens River and the creeks tributary to the line of the Aqueduct above Haiwee Reservoir is sufficient to maintain this reservoir at a stage representing never less than five-sixths of full capacity during the most critical period covered during the period of record (January 1, 1904, to date), when the average draught upon the system is one-half of the ultimate contemplated development, namely 136 million gallons per day. To maintain the reservoir two-thirds full during a critical period of the same severity as that just referred to when the works are developed to the point where the average draft is 272 million gallons per day will require a supplementary supply either from the ground or from storage in reservoirs constructed along the upper reaches of Owens River. It is the present intention to develop this auxiliary supply from the extraordinarily large underground resources of the Independence region by means of wells. It would also be completely possible to develop it, it is believed, through the storage of flood waters in the proposed Long Valley and Tinemaha Reservoirs, one or both, as might be found needful. The opportunities for such storage, especially in Long Valley, appear to be remarkably good.

To maintain Haiwee Reservoir half-full of water under the conditions stated will demand a maximum rate of supplementary feeding (from wells or other storage) of about 140 million gallons per day. The average daily demand during this most critical period would be about 75 million gallons. An extended series of observations in Owens Valley (see United States Geological Survey Water-Supply Paper No. 294) has demonstrated conclusively that a system of wells can readily be developed to yield the total quantity of water demanded by the conditions in question at the maximum rate just noted. The storage and underground water studies forming the basis of conclusions just stated were made by Mr. Charles H. Lee.

The sound deduction from all of these studies whose results were largely presented in the City's behalf during the hearing before Judge Works, must be: (1) that the storage may readily be maintained at the stages assumed during the most critical period covered by the record to date—and this period, September 3, 1912, to October 31, 1913, must be regarded as representing an extraordinary drought such as has probably seldom occurred in California in modern times—and (2) that, if such storage is maintained, the time factor will be so great as to represent the highest possible efficiency in the destruction of pathogenic bacteria, should they appear in the sources of supply, thereby rendering the water safe and wholesome when delivered to consumers in the city.

QUALITY OF WATER FROM AQUEDUCT SYSTEM

Chemical Composition of Water

The witnesses for the plaintiff notwithstanding, it seems to be perfectly true that all up-to-date competent authorities are now agreed that organic matter in water, at least in any reasonable amount which is likely to obtain in surface sources, even those which are heavily charged with sewage, is quite without significance if harmful bacteria are absent. Chemical analysis is unable to give any definite information with respect to the character or number of bacteria present. It may be concluded that the so-called sanitary analysis, which attempts to determine the amount and state of nitrogenous matters dissolved or suspended in the water has practically served its day and, except in certain routine work and for special cases and conditions, must be relegated to the past. Nowhere else does the impossibility of consistent interpretation of this sanitary analysis appear quite so prominently as in so-called expert testimony where the parties to the suit on the same data are trying to demonstrate different conclusions.

The attorney for the plaintiffs spent a great deal of time during the hearing of the cases in question upon the results of certain chemical analyses collected from the aqueduct system and from Owens River and its tributaries at various points on two different occasions. The learned witnesses who interpreted the results of the analyses pronounced the water from Haiwee Reservoir and all points below as entirely unsafe and unfit for drinking purposes. They pictured the horrible ptomaine and toxic catastrophes which would visit death and destruction upon the innocent inhabitants of Los Angeles should the wicked Board of Public Service Commissioners permit this vile fluid to be supplied for domestic uses.

As a check upon the analyses produced by these experts, the analysts for the city also collected water from the various parts of the system and made these so-called sanitary analyses upon them. The results of the two groups of analyses were not hopelessly different if exception is taken with respect to the results of certain analyses which one of the witnesses for the plaintiff made on samples which were stored for as many as ten days before the analytical work was performed.

It may be interesting to compare the analyses of samples collected at the intake of the Aqueduct on Owens River with those of Massachusetts water supplies derived from 153 surface sources for which records extending over long periods have been systematically obtained. The average analyses for the five-year period 1905-1909 for 110 sources out of the total number of 153 were as high or higher with respect to free ammonia, 144 sources were as high or higher as respects albuminoid ammonia and 15 sources were as high or higher with respect to nitrates. The nitrite content of surface waters was not summarized in the Massachusetts statistics referred to (41st Annual Report, Massachusetts State Board of Health, 1909, pages 201-225), perhaps because it was too variable and uncertain to be of interest.

The results of analyses of samples collected further down in the system, near the point of distribution, namely in the section between the San Fernando Reservoirs and Franklin Reservoirs, may be of interest as compared with the results for the same group of Massachusetts surface water sources above referred to. Of the total of 153 sources represented, 14 were as high or higher with respect to free ammonia,

58 as high or higher with respect to albuminoid ammonia and 3 as high or higher with respect to nitrates. No one has ever discovered or complained that the state of health in the various communities having these higher amounts of nitrogenous material in their drinking waters was not fully as good as that in the communities having water supplies extraordinarily low in organic composition.

In order to show what effect, if any, the drinking of waters heavily charged with organic matter might have upon the health of consumers as compared with those low in organic content, the general death rates in 15 Massachusetts cities and towns deriving their water supplies from storage reservoirs containing the largest amounts of albuminoid ammonia and high free ammonia were compared with those of 15 other cities and towns in Massachusetts whose water supplies from storage reservoirs were generally lowest in albuminoid ammonia and low in free ammonia. The analyses and vital statistics covered the same period, namely the five-year period, 1905-1909, inclusive. The study showed that the general death rates in the two groups of cities were practically identical, being 0.01 per 1,000 higher in the cities supplied with waters lowest in organic content, as represented by albuminoid and free ammonia.

The mineral composition of the water derived from the Aqueduct system was not projected into the hearing of the cases. On this feature there can be no controversy. Daily samples for the entire year 1908 were collected from Owens River just above the Aqueduct intake and were analyzed for their mineral composition in 10-day composites in the laboratories of the United States Geological Survey. The water was found to carry only 16 parts per million of turbidity. The suspended matter causing the turbidity was found to be extremely coarse and capable of settling almost completely out of the water in a very short period. The average turbidity is only 13% of the average of the Sacramento River at Sacramento, 15% of that of the Potomac River at Washington, 30% of that of the Susquehanna River at Harrisburg, 41% of that of the Delaware River at Philadelphia, and 55% of that of the Hudson River at Albany. The maximum turbidity of Owens River water was found to be only about 3 or 4 times the average. The maxima turbidities of all of the streams mentioned above are many times the average values for these rivers.

The total hardness of the water of Owens River was shown not to be excessive when compared with that of the majority of the water supplies of the municipalities in California. The supplies of Alameda, Berkeley, Fresno, Oakland, Pasadena, Redlands, Riverside, San Bernardino, San Diego, San Francisco and Stockton all have an average total hardness greater than that of Owens River. The Los Angeles River supply at the headworks has a total hardness 150% greater, and at Crystal Springs a hardness 67% greater than that of Owens River water.

Bacteriological Composition of Water

All analyses show that at the inlet of Haiwee Reservoir the Aqueduct supply contains considerable numbers of bacteria of the species developing on agar at 37° C. In the eight samples taken by the analysts of both parties to the suit and whose analyses are available, the numbers ranged from 50 to 2,100 per cc. Four, or 50%, of the samples were negative for B. coli. In two of the other samples the organism was present in 10 cc. and in the remaining two samples it was present in 1 cc.

Eight samples of water were collected for bacteriological analysis at the intake of Haiwee Reservoir by Messrs. Wilson and Brem for the city. The counts on agar ranged from 60 to 1,800 per cc. and averaged 800. B. coli was not found in any of the samples. The analysts for the plaintiffs in the two sets of samples collected at this point succeeded in finding B. coli in 0.4 and 0.5 cc.

On general principles, as enunciated above, it is obvious that real interest should center in the bacteriological character of the water of the Aqueduct system as delivered to consumers in Los Angeles. Many samples of water were collected by the analysts for the City at various times at points carefully selected to represent as comprehensively as possible the entire area in the city supplied by the Aqueduct works. These were all examined in accordance with the most rigorous procedure with the following results:

Name of Analyst	No of Samples Examined	Average Total Count*	B. coli Neg. in 10 cc.	Pos. in 10 cc.	Pos. in 1 cc.
Black	13	60	12	1	0
Brem	23	210	15	8	0
Wilson	23	330	21	2	0

*On agar at 37° C., 24 hours.

The results are surely very satisfactory. B. coli, the typical intestinal organism of both man

and animals, were not found once in 1 cc. in the 59 samples represented. They were found in 10 cc. portions of 11 samples or in about 23% of the entire number examined. Considering the newness of the reservoirs, the large numbers of water fowl thereon and the (temporary) exposure to animal contamination in San Francisquito Canyon, it seems wholly reasonable to conclude that the intestinal organisms found were entirely from animal sources and had no sanitary significance.

The significance of the presence of B. coli in a water supply rests, of course, in the fact that if intestinal germs are present from human sources, the pathogenic bacteria which cause the water-borne diseases may also be present. In so far as the opinion of sanitarians has been crystalized at all with respect to the significance of B. coli in surface waters, it would seem to be that the occasional presence in 10 cc. or even in 1 cc. has but little sanitary significance. If this organism is persistently present in 1 cc. of samples examined there is good ground for the belief that the source is no longer harmless animal pollution but rather the more constant and dangerous wastes from human beings.

An interesting side light was thrown upon the theory that water fowl might be responsible for the B. coli found in the waters of Franklin Reservoir and in part for those found in the other storage basins of the system. Two wild duck were shot in Upper Franklin Reservoir and their intestinal tracts were examined for B. coli. This organism was present true to type in enormous numbers in each case, the average being about 50,000,000 per gram of dejecta in the intestinal canals.

It is a striking and significant fact that the chief witness for the plaintiff made no bacteriological examinations whatever of the water from the Aqueduct system as delivered to consumers in Los Angeles. Two samples only were reported by another witness. Both samples were taken at the same date at the residence of E. M. Frost. The total count was given as 110 per cc. (presumably after 72 hours incubation at 37° C. on agar). B. coli were reported as absent in 5 cc. of one sample, and as identified in 1 cc. of the second sample. It is difficult to state how much value may be placed upon the work of this witness since, during cross-examination in the hearing before Judge Works, she naively admitted that she had been employed to find pollution and that samples which did not show such conditions were discarded.

Possibility of Disinfection of Entire Water Supply

It has now become possible to effectively disinfect public water supplies in the largest volumes at an extremely low cost and with the minimum of attention employing either liquid chlorine or hypochlorite of calcium (bleaching powder). If at any future time it is desired—for æsthetic reasons or to "make assurance doubly sure"—to virtually sterilize the water by either of the methods stated, it can be done. The conditions at Lower Franklin Reservoir are ideally devised for such treatment so that the water entering the distribution system from the Aqueduct system may be rendered not only practically free from B. coli, as at present, but also practically free from all bacterial life.

Chlorination of the supply from the Los Angeles River works has now been undertaken and is producing excellent results. All bacteriological samples collected from this source during the preparation of evidence for the hearing of the cases in question and prior to the installation of chlorinating devices were found to contain B. coli. These were present in 91% of 1 cc. samples and in 10 cc. of all samples.

The Aqueduct Supply as Fulfilling Rigorous Quality Requirements

In the earlier days of water works engineering but little attention was paid to the sanitary character of the supply. The principal object was to secure a sufficient quantity of water. Gradually, with the development of a knowledge of bacteriology and a growing appreciation of the intimate relationship between water supplies and disease, the demand has arisen not only for abundance but also for safety and æsthetics as comprehended by freedom from disease germs and as far as possible from all bacterial life and by good appearance and taste. Today the requirements of quality and quantity must be considered of equal and absolutely essential importance. The failure of a water supply to meet either of these fundamental requirements must be considered as a real delinquency entailing a definite burden which must be borne by the community.

The production of safety as well as of good appearance in a public water supply has a sanitary and æsthetic significance which cannot be measured by any financial standard, important as this may be. The real test is not the quality at the source; it is the quality at the point of use. These finer qualities in a water supply bespeak progress, they imply additional safe-

ty and comfort in living and in so far as water supplies have to do with these matters, purity means better general health, a real conservation and promotion of those forces which may be regarded as the vital assets of the community. Indeed, the simple fact that its water supply is at all times safe, wholesome and attractive, rather than dangerous and of ill appearance, is an asset of very material worth to any community. The opinion of sanitary engineers, sanitarians and in general those who are familiar with the development of water supply standards, has now become crystallized with respect to the requirements which the supply and works must fulfill. These requirements are sanitary, æsthetic, commercial and protective in their nature. They may be summarized as follows:

(a) Quality

(1) Primarily the water supply must be free from pathogenic or disease-producing organisms. More than this, it should be free from those allied organic forms which may not as yet be recognized as accompanying disease, but which may nevertheless not be conducive to health. This condition of safety must prevail continuously and the supply must not be subject to what may be termed "accidental" contamination.

(2) The water must be uniformly clear and free from turbidity, both that which may be produced by suspended mineral matters, and also that which may be due to suspended organic (vegetable and animal) growths or impurities.

(3) The water must not be discolored by dissolved vegetable matters to such an extent that it may be objectionably apparent when employed for table use or in the arts.

(4) The water must at all times be free from both tastes and odors, either those produced by dissolved gases or those which may be due to the growth and decay of micro-organisms (minute plants and animals frequenting lakes, reservoirs and rivers, but usually prevailing to the least extent in the last named source).

(5) The water should be reasonably soft and of sufficiently low mineral content so that it shall be satisfactory in this respect not only for domestic purposes but for steam making and other industrial and commercial uses.

(6) As far as possible the water should be cool and palatable.

(b) Quantity

(7) The supply must be abundant and unfailing, but for economic reasons must be conserved in such manner that all preventable waste shall be eliminated.

(c) Dependableness

(8) The pressure under which the water shall continuously act in the distribution pipes must be ample to serve the various districts according to their specific character and needs.

(9) The system of works must be one in which design and construction may be executed in such a way that they will successfully meet conditions imposed by the natural phenomena occurring or likely to occur within the region in question.

(10) The various structures in connection with the system of water works should be so located, arranged, built and protected that they may not be unduly exposed to fires or other accidents befalling neighboring structures.

The requirements which have been outlined above are not more exacting than the principles of sanitary science, aesthetics, economics and safe engineering demand; in fact, they are only rational requirements upon which the public at large, gradually educated to higher ideals, will become more and more insistent as time goes on.

It is pertinent to inquire how completely the character and conditions of the Aqueduct supply at the point of use do and will measure up to the ideal standards pronounced above. With respect to the several qualitative standards we may conclude:

(1) That the supply is now and will remain at all times practically free from all pathogenic bacteria. If chemically treated according to recently devised, cheap and readily applicable methods—to which the distributing works are peculiarly well adapted, as explained hereinbefore—it will become practically free from all bacterial life. It may safely be assumed, however, that the present bacterial composition is not unsatisfactory and is entirely without sanitary significance. As soon as the "newness" of the reservoirs wears off and the permanent shore lines become established there is not the slightest doubt but that the ordinary bacterial content of the supply will be naturally and substantially decreased.

(2) That the water delivered to consumers is and will be clear, and especially so when, with increasing age, the permanent shores of the reservoirs become established. Lower Franklin Reservoir, which is the last in the series in the Aqueduct system and wherein the water is stored immediately before it is

delivered to consumers, is ideally contrived to prevent the growth of algæ and other micro-organisms, as well as of bacteria, by the use of chemicals.

(3) That the water of Owens River and its tributaries is practically colorless and free from vegetable stain. There is no reason to believe that its character in this respect will deteriorate in passing through the Aqueduct system.

(4) That under the conditions which do and will obtain, and in view of the fortunate situation with respect to Lower Franklin Reservoir as just noted in (2) above, the aqueduct supply will always be satisfactory from the standpoint of odors and tastes. All storage reservoirs are more or less subject, at intervals, to the growths of micro-organisms. By modern methods these can be effectively controlled.

(5) That as noted on page , the Aqueduct supply is much softer than the supply derived from Los Angeles River. It is softer than the majority of the water supplies of the larger cities in California.

(6) That the conditions as respects coolness are matters dependent upon the climate and the depths to which the water mains are laid. With the control of growths of micro-organisms in the reservoirs, and particularly in Lower Franklin Reservoir, there is every reason to believe that the water will continue to be palatable as it is at present.

The water resources of the Aqueduct system have been discussed at some length in the preceding pages. All of the studies which have been made demonstrate that the volume of supply for which the system has been designed can be developed and can be maintained at all times and under all conditions.

It is not the purpose of this paper to discuss the structural stability and other features having to do with the dependableness of the works. Most of the structures have already been tested through a considerable period. They have proved their ability to stand and to perform the services for which they were intended. Indeed, it can be stated without reservation that this magnificent enterprise, now all but completed, has been carried through in a marvelously enduring fashion with an economy which has won the enthusiastic praise of the whole engineering world.

CONCLUSION

Decision of Judge Works

No more suitable or fitting conclusion to this discussion could be offered than the decision of Judge Lewis R. Works, before whom, in Department Four of the Superior Court of Los Angeles County, the cases of Hart and Frost vs. the City of Los Angeles were heard. The written decision was rendered shortly after the arguments of counsel were concluded. The text of the decision is as follows:

"This litigation was instituted for the purpose of enjoining the further delivery of a water supply from Owens Valley to the people of Los Angeles. It proceeds mainly upon the claim that the water is polluted and infected, is likely to continue so, and is therefore unfit for human consumption. This claim has been urged strenuously throughout the trial and the defense waged against it has been equally vigorous. Counsel on both sides have been vigilant, aggressive and untiring throughout the controversy. One hundred and fifty photographs and maps have been introduced in evidence and about three hundred samples of water, taken at various points from the headwaters of Owens River to kitchen taps in Los Angeles, have been analyzed for the information of the Court. Men and women of a high degree of learning in hydraulics, in bacteriology and in analytical chemistry have testified, the respective counsel have been allowed the widest possible range in the introduction of the evidence and the subject has been exhausted. The hearing has consumed forty actual trial days.

"Owens River and its tributary creeks flow through a country given to cattle raising and other rural pursuits, and it is not denied by the defendants that these streams are contaminated to the extent that is necessarily characteristic of all waters flowing through such a country, and having a similar population. In this connection it is to be noted, however, that the watershed of the Owens River is peopled by an average of but about one and one-half persons to the square mile, while many of the cities of the world take their water supply from surface streams the drainage area of which is populated to the extent of several hundred persons to the same area.

"The scientific principles governing the selection and operation of a water supply system intended to furnish a domestic supply

COTTONWOOD CREEK DIVERSION OVER CONDUIT—(VIEW TAKEN FROM ABOVE)

from surface streams require a treatment of the water in order to rid it of the contamination which is inevitably incident to such a source of supply. This treatment consists in either the use of chemicals, the installation of filtration plants, or in the storage of the water in reservoirs for a period of time requisite to its purification.

"If it be granted that the waters of Owens Valley are contaminated like all surface waters, the density of population of its drainage area being the true index of contamination, and if it be granted that, for that reason, those waters would not be proper for domestic use at the intake of the Los Angeles Aqueduct, in the valley, does it follow that the water has not been purified when it reaches the point of delivery in Los Angeles, two hundred eighty-six miles from the intake? In other words, is the water, during its transmission from the intake to the City, subjected to either of the methods of treatment above mentioned as requisite to the purification of a surface water supply?

"Ninety miles from the Aqueduct intake is located Haiwee Reservoir. From the outlet of that reservoir to Los Angeles is one hundred ninety miles. During its progress over that distance, the water supply is halted, even if briefly, in Fairmont, Dry Canyon and Franklin Reservoirs, three other basins having some value for storage purposes.

"A large portion of the testimony during the trial has been directed to the question of the efficiency of the entire system mentioned, and especially of Haiwee Reservoir, as a purifying agency, and many experiments have been conducted in the waters of the reservoir in order to determine the problem. It is not necessary now to state the nature of these experiments, nor to analyze the theories and arguments advanced by the various expert witnesses who have testified concerning them. It is sufficient to say that the great weight of the evidence demonstrates that Haiwee Reservoir is remarkably efficient as a great purifying unit in the Aqueduct system. This immense basin is over seven miles in length, with that distance between its inlet and outlet, and impounds, for a long period of time, certainly not less than thirty days, all waters which enter it. The reservoir is peculiarly adapted to the use for which it was principally designed. One of the leading expert witnesses in the case characterizes it as unique among the storage reservoirs of the world. Being in a region in which there is a rainfall of not to exceed five inches per annum, a region of porous, sandy soil, and entirely uninhabited, it is the recipient of no run-off from its own watershed and it is therefore free from the contamination of such a run-off. The only influent of the reservoir is the Los Angeles Aqueduct, containing waters brought from the Owens River. The intake gates on the river may be closed at will and there are frequent waste gates along the course of the Aqueduct, from the river to the reservoir, through which the waters of the great ditch may be entirely cast away. These instrumentalities conduce to a perfect control of the Haiwee influent and the waters may be divered and wasted in periods of flood or at any other time of possible undue contamination from whatever cause.

"This peculiarly advantageous location of Haiwee is mentioned in passing, only, as the period of storage which is allowed by its size and shape is alone sufficient to guarantee to the people of Los Angeles a positive immunity from dangers residing in the waters before they leave Owens Valley, conceding that such dangers are there present, and without regard to the use of the waste gates mentioned, which furnish but an added factor of safety to a system safe enough without them.

"The Los Angeles Aqueduct is so planned as to secure to the residents of Los Angeles a palatable, wholesome and entirely sanitary water supply and Haiwee Reservoir is the prime element of safety.

"The conclusions reached in this opinion do not come from a mere preponderance of the evidence, but from an overwhelming weight of proof which leaves possible no other termination of the litigation. On the whole, the record in this trial furnishes a splendid vindication of the judgment of the people of the city in acquiring and developing a water supply from the Owens River region.

"The application of the plaintiffs for an injunction is denied and the defendants will have judgment for their costs."

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